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The Golden Gate Road, near the entrance to Swan Lake Basin.

Cleopatra Terrace, formed by water from the Diana Spring.

THE GEOLOGY OF THE YELLOWSTONE NATIONAL PARK.—[See page 7.]

Actual Instances of Dual Personalities—I*

Cases in Real Life That Rival the Wildest Fiction

By Edward Tyson Reichert, M.D., Sc.D., Professor of Physiology in the University of Pennsylvania

The noted English author, Mr. H. G. Wells, was asked, "What is the first step toward literary production?" and he is accredited with the reply: "It is imperative, if you wish to write with any power or freshness at all, that you must utterly ruin your digestion." Perhaps in such a light the originality of the stories of "Dr. Jekyll and Mr. Hyde" and "The Case of Becky" may suggest to some of you the outpourings of abnormal minds, but we find in the histories of the lives of some who have lived before or with us abundant inspiration for such fiction.

When we speak of an individual's personality we have reference to the sum or totality of his mental traits, which traits are expressions of correlations of the past with the present, and not only of his individual past, but also of the lives of ancestral generations which have left their impression on his mental processes. Personality is a manifestation of an extremely complex aggregate of interassociated and interacting mental states—a combination that is so plastic that one or more of the components may become suppressed or exaggerated, and thus transiently or permanently impart to the individual mental characters that are more or less at variance with his recognized identity.

All are aware of the transitional character of our personalities in our every-day lives, as is expressed especially by our variable moods; by the duplicity of personality of the habitual one-day saint and six-day sinner; by the ease with which the actor assumes different personalities, associating with each such traits as characterize the subject; and by the changes brought about by intoxicants—the quiet, kind, loving, moral, cultured man, becoming quarrelsome, brutal, lewd, profane, and utterly lacking in the high ideals that characterize his normal life. We know too that in somnambulism, delirium and certain hysterical states the individual may exhibit mental traits which in many respects are markedly or wholly different from those which typify his normal life; that hasheesh and certain other drugs may produce in the subject a delusion of an existence of a double personality, that is, a sense of having two mental lives which may hold communication; that in certain forms of insanity the individual has the belief of a dual mental and physical existence, even becoming obsessed with the delusion that he is not himself but his double; and that the mental life of normal, hypnotic and narcotic sleep is usually quite different from that of the waking state. But none of these instances is to be included in the category of dual personality because in each there is merely a single personality that has become modified in normal or abnormal ways, whereas in cases of dual personality there are two mental individuals belonging to one body, both sane, each having self-consciousness, and each having its own characteristic mental life.

There can be no question of a close relationship between the psychic states of somnambulism, hysteria, delirium and insanity with those of dual personalities, and it may not always be possible to definitely differentiate them. Where insanity begins and sanity ends no one knows—who can tell whether or not certain people are sane or insane? Similarly, where modifications of a single personality end and dual personalities begin no one can say, yet in both instances there are well-defined types that are so definitely characteristic that we can declare positively that there is one or the other. It is such types that must be studied at the outstart if we are to have clear conceptions of class distinctions and understand the psychology of these extraordinarily interesting cases of two different minds belonging to one body.

Typical cases of dual personality are characterized by the existence of two distinct, sane, self-conscious mental lives belonging to one body. The change from one personality to another is usually abrupt, without obvious cause, and commonly following a period of loss of consciousness, usually sleep, which commonly is long and profound. Upon the return of consciousness there exists a partial or complete loss of memory of the knowledge that particularized the individual's life, this loss being associated with a change of character, so that the subject is to all intent and purposes another mental individual, having a different memory, will, disposition, intellectual powers and habits of mind and body. The acquired personality or secondary state may have no recognition of the existence of the primary or normal state, or *vice versa*; its mental and physical lives may be so entirely different from those of normal life that if reversion occurs to the primary state his secondary state may, as it were, be completely blotted out, so that mental existence is resumed where it ceased when the secondary state appeared, the subject having no knowledge of his life in the interim. In some instances there occurs repeated alternation of the two personalities, and in such cases one personality may at once, or in the course of time, recognize the existence of the other, the subject becoming conscious of a dual mental existence, eventually blending the two, or adopting one or the other permanently, and not infrequently the secondary, or supposed secondary, state. Sometimes there appear multiple personalities, that is, as many as ten or more personalities may be developed, one succeeding another, each differing from the others, each being as characteristic as though the individual had been as many times reborn. And so one might go on indexing these varied and uncanny manifestations of mental life which seem more like freaks and monstrosities of the imagination than actualities of life. Perhaps as many as forty cases of dual and multiple personality have been reported, some of which have been republished time and again, yet they are almost unknown even to the medical profession. Undoubtedly a very large number have existed, and many of the unfortunate subjects found lodgment in insane asylums and prisons.

Turning our attention now for a few minutes to fiction, and first to Robert Louis Stevenson's story of Dr. Jekyll and Mr. Hyde, Dr. Jekyll is described as a large, well-made, smooth and handsome-faced man of fifty, with perhaps something of a slyish cast, but with every mark of capacity and kindness, and who cherished sincere and warm affections. He was a connoisseur, inclined by nature to industry, and fond of the respect of the wise and good. The worst of his faults was a certain impatient gayety of disposition, such as has made the happiness of many, but such as he could not reconcile with his imperious desire to carry his head high and wear a more than commonly grave countenance before the public. Hence, while he indulged he concealed his pleasures, hiding them with an almost morbid sense of shame, and standing committed to a profound duplicity of life. He saw that two natures contended in the field of consciousness and he conceived of the separation of these natures by taking a drug, and of recombining them by an antidote.

Upon taking the potion, agonies were caused which swiftly subsided, and as if out of a great sickness he came to himself in the form of Mr. Hyde, a man tenfold more wicked than his primary self and sold a slave to his original evil. As Mr. Hyde he was dwarfish and gave the impression of deformity without namable malformation. He had a displeasing smile and bore himself with a sort of murderous mixture of timidity and boldness. He spoke in a husky, whispering, and somewhat broken voice, and his manner aroused disgust, loathing, and fear. He seemed hardly human and was inherently malign and malicious, taking pleasure in the infliction of every degree of torture. He had the name of Satan written on his face. Mr. Hyde, drinking the antidote, cried, reeled, staggered, clutched at the table, staring with injected eyes and gasping with open mouth, pale and shaken and half fainting, was transformed to Dr. Jekyll. The two natures had memory in common, but all other faculties were most unequally shared between them.

Transitions from one state to the other were frequent, and in time Dr. Jekyll, like those of us in everyday life who habitually give way to evil inclinations, lost hold, as it were, of his original and better self, and became slowly incorporated with his secondary or worse self in the form of Mr. Hyde. He soon came to a realization that he had to choose between the two, and choosing the better, he for two months was Dr. Jekyll. Then, in an hour of moral weakness, he again swallowed the transforming potion, and instantly the spirit of hell awoke and raged in him, and again was he the moral monster, Mr. Hyde.

"The Case of Becky," while presenting certain features in common with those of Dr. Jekyll and Mr. Hyde, is in its manifestations of the secondary state and in certain other respects quite different. The story of Dr. Jekyll and Mr. Hyde belongs to the category of drug fiends we read of from time to time in the daily press; but "The Case of Becky" is one of dual personality, and the conceptions of the author are well founded in histories of cases in life which are even more weird and interesting, and seemingly improbable.

In normal life the person of Becky was known as Dorothy. Dorothy, it will be recalled, was the step-daughter of an unscrupulous, itinerant hypnotist. She was made by him a hypnotic subject, and grew up amid surroundings such as would naturally tend to develop in a very sensitive girl abnormal mental states. She in time fled in terror from her degenerate and conscienceless stepfather, to be found after some years in a sanitarium, where we are made familiar with her dual lives. As Dorothy, she was a highly sensitive, charming and lovable young woman; sweet tempered, fond of reading, and with exemplary habits of mind and body. At times upon awaking from a short sleep she would exhibit a personality which was the very antithesis of the normal. In this state she was known as Becky. She was quarrelsome, disagreeable, used coarse language, was profane, tore her clothing, and took great delight in annoying those about her, and played all sorts of disagreeable tricks upon her primary self, which appeared to her as the person of another individual, hiding and destroying things which she imagined belonged to this hated person.

Mr. Belasco, in the staging of "The Case of Becky," showed remarkable skill. Dorothy was a very impressionable girl who, because of abusive treatment and repeated subjection to hypnosis by her stepfather, had her mind so peculiarly affected as to become a victim of self-hypnosis and to lead to the development of a second personality entirely different from her normal. After the appearance of the second personality an alternation of the primary and secondary states took place for years, until finally, under the care of an expert neurologist, she was, through hypnosis restored to her normal self. Such cause, effect and cure are wholly in accord with the facts of science, although perhaps exceedingly few of the audience, and very few critics, looked upon them as being otherwise than entirely imaginative.

What seemed to be the most vulnerable feature of the presentation was Dorothy's consciousness of the presence of her stepfather in some way other than by her ordinary senses—in some occult manner, such as by telepathy, that is, by an influence of one mind over another at a distance by other than the normal channels of communication. But this very point, seemingly small and unimportant to the lay mind, was not overlooked by so skillful a stage craftsman. Those who followed the play with discernment will recall that at a moment before Dorothy appeared on the stage in a self-hypnotic state her stepfather, who was unseen at the time, had coughed loudly and in a strikingly peculiar way—a cough which we are supposed to understand was heard throughout the sanitarium. It was this cough which was intimately related to the horrors of her girlhood, though not consciously recognized by Dorothy, that so affected her peculiarly sensitive and abnormal mind as to throw her into hypnosis. In this condition she was en rapport with her stepfather, extremely sensitive to his presence, and almost wholly submissive to his will. Even in the hypnotic state she has some consciousness of her well-nigh helplessness and the perils that encompassed her in the presence of her stepfather. To dissipate the tendency to self-hypnosis and prevent the recurrence of the secondary state by hypnotic suggestion, in accordance with the play, may seem to be visionary, yet it is entirely consistent with the facts of science. The presentation of the dual character was remarkably true to life.

Turning now from fiction to strange stories from life, we find that the essential features of "The Case of Becky" have their counterpart in the history of the case of Miss Beauchamp, which was published by Dr. Morton Prince ("The Dissociation of Personality," 1905). The subject was a person in whom three personalities spontaneously developed, each being distinctly different from the others in trains of thought, views, ideals, temperament, acquisitions, tastes, habits, experiences and memories. Only one of the three had any inherent knowledge of the others, and the other two had no knowledge of each other or of the first except such as had in time been obtained by inference or by information from other people. Suddenly we find one personality vanishes and another appears in kaleidoscopic succession, each being ignorant of what was said or done or where she was while in the immediately preceding personality. For six years these three personalities played a remarkable and almost unbelievable comedy of errors, making their entrances and exits in a most inexplicable way, each for a time playing her part, each being as individualized mentally and physically as though there were three persons having quite different personalities.

Miss Beauchamp is described as having been a nervous, impressionable child, given to day-dreaming, living in

* A lecture delivered at the University of Pennsylvania, December 19th.

her imagination, unduly influenced by her imagination, living in a land of idealism, and seeing people not as they are but as she imagined them to be, and lacking in true conceptions of her environments. She was intellectually keen and fond of books, and she idolized her mother, who, however, was devoid of affection for her, the effect of which was to make her morbidly reticent and live within herself and her imagination. When eighteen years of age a nervous shock played the principal role in the development of the remarkable personalities that for some years encompassed her life. At twenty-three she was a college student, ambitious, over-conscientious, mentally and morally stubborn, very nervous, a neurasthenic of an extreme type, and a continual sufferer mentally and physically, becoming worse, and ultimately unfitting her for work.

In the course of time two personalities developed which came to be distinguished as Sally and the Idiot. The three personalities (Miss Beauchamp, Sally and the Idiot) were so different as to suggest the designations The Saint, The Woman and The Devil.

Inasmuch as Miss Beauchamp was a physical wreck, it might naturally be assumed that her bodily ailments would be carried into her other states, so that notwithstanding great changes in mental traits her bodily traits would continue the same. But this did not occur, thus showing in an extraordinarily impressive way the potent influences of the mind over the body. While Miss Beauchamp was always ill, always suffering, always physically weak and incapable of more than very little physical and mental exertion, the Idiot showed a markedly lessened neurasthenia and was capable of physical and mental exertion much beyond the powers of Miss Beauchamp, yet with distinctly less capacity than Sally. As Sally, the Devil, she was a stranger to illness and had remarkable physical endurance, knowing neither fatigue nor pain. While in the state of Sally she would take long walks, far beyond the physical strength of Miss Beauchamp, and then suddenly Sally would vanish and the body be returned to Miss Beauchamp, who would come to herself in a state of utter exhaustion notwithstanding that only a few moments before, as Sally, there was physical vigor.

Miss Beauchamp and the Devil in their physiological and moral tastes, moral characteristics and acquisitions were almost wholly antipodal. The kinds of food and drink liked by one were disliked by the other. Miss Beauchamp's appetite was poor, she cared little for the pleasures of the table, never used vinegar or oil, and was very fond of ice cream and broths, etc. The Devil had a good appetite, enjoyed the table, used freely vinegar and oil, never ate ice cream or broths, etc. Miss Beauchamp wore her hair low and her clothing loose, and was fond of church and devotional books. The Devil wore her hair high and her clothing tight, and never voluntarily entered church or read devotional books. Miss Beauchamp was patient, considerate of others, amiable, hated sewing, and was very fond of children. The Devil was most impatient, most inconsiderate, unamiable, given to rages of violent temper, liked sewing, and looked upon children as a great nuisance. Acquisitions of Miss Beauchamp were often not possessed by the Devil, and those of the latter not often by Miss Beauchamp. And so in very many ways one personality was the antithesis of the other.

Sally is described as having a character, trains of thought, memories, perceptions, acquisitions, and mental traits generally which were quite different from those of Miss Beauchamp. Sally claimed that she knows what Miss Beauchamp thinks, says, writes and does, sees what she sees at the time, and not as knowledge afterwards acquired. Curiously enough, while Miss Beauchamp could hide absolutely nothing from Sally she was absolutely without knowledge of the existence of Sally, and Sally, while recognizing the existence, thoughts and so on of Miss Beauchamp, did not associate Miss Beauchamp with herself or her body, but imagined her to be another individual. Sally had a jealous hatred of Miss Beauchamp, and remarkable and almost incredible were the pranks, torments and terror to which Miss Beauchamp was subjected. The personalities of Miss Beauchamp and Sally frequently alternated. A favorite form of Sally's amusement was to suddenly vanish and restore the body to Miss Beauchamp under conditions that would give rise to great mental and physical suffering. Sally would write most annoying letters to Miss Beauchamp, and she had a most subtle way of stating just enough to cause Miss Beauchamp's imagination to run riot and to fancy all sorts of things, and generally to create a state of mind full of apprehension, or even terror. Sally would make engagements which she knew Miss Beauchamp could not keep, and often Miss Beauchamp would awake to find that she had unknowingly done something entirely different from that which she had contemplated. Miss Beauchamp's promises were broken and engagements were made which were objectionable, or even of such a character as she could not in honor keep. Sally would write letters exposing the private affairs of Miss Beauchamp, and by distorting, exaggerating and deliberately lying she caused the keenest sense of mortification and increased the illness of Miss Beauchamp by the intense anxiety.

Sally took advantage of Miss Beauchamp's carelessness about the care of money, and many were the torments to which the latter were subjected. One day Miss Beauchamp was sorely worried over the mysterious disappearance of some money. Sally had hidden it and written a note to Miss Beauchamp, which was received a day later, telling Miss Beauchamp that she was too negligent and incapable of taking proper care of money, and that she would accordingly be put on an allowance of ten cents a day with which to amuse herself. For some time thereafter Sally doled out sums of two, five or ten cents, and then would vanish, giving back the body to Miss Beauchamp.

For two years this extraordinary and almost incredible play of comedy, farce and drama of different personalities in one body went on in alternation.

Miss Beauchamp was repeatedly hypnotized by Dr. Prince, and in the course of time there developed a half-hypnotic state in which there occurred a personality different from the other three. She in this state had a full knowledge of the events of the past six years. She now seemed to be without the morbid idealism and impressionability so strongly marked in the personality of Miss Beauchamp, and was also without the melancholy sadness and weariness, and was less nervous and humble. She was light-hearted, natural and physically strong, and possessed greater spontaneity and intellectual grasp. This personality appeared to be the fused personalities of Miss Beauchamp and the Devil, a personality that had lost the morbid emotional idealism of the former and the impishness, temper and willfulness of the latter.

Naturally, the question arises as to which, if any, of these personalities is to be regarded as the real Miss Beauchamp. Dr. Prince answered this question by showing the real Miss Beauchamp is not the Miss Beauchamp we met at the beginning of our recital, but the fused personalities of Miss Beauchamp and the Idiot he brought about and rendered permanent by hypnosis. The personality of Miss Beauchamp as we first knew her was, like the personalities of Sally and the Idiot, a dissociated or detached mental state, the other mental states being for the time latent or submerged. What became of Sally? The mental state represented by Sally seems to have been a subconscious state that became dominant because of the splitting of the primary self into two parts, one part becoming suppressed. The union of the personalities of Miss Beauchamp and the Idiot gave rise to a personality of such potentiality that the personality represented by Sally was submerged in subconsciousness. The personality of the real Miss Beauchamp after a period of vascillation had continuous existence, and Miss Beauchamp was thereafter a mentally and physically strong individual.

In the case of Miss Beauchamp, it will be recalled that while Sally had full knowledge of Miss Beauchamp and the Idiot, the Idiot had only a scrappy knowledge of Miss Beauchamp and no knowledge whatsoever of the existence of either Sally or the Idiot. In the case about to be referred to, the secondary personality, unlike Sally, had no knowledge of the primary state, nor had the primary state any knowledge of the secondary. The secondary personality, curiously enough, played pranks similar to those of Sally, but not upon her own person.

(*To be continued.*)

Odessa, the Grain Port of Russia

Odessa is one of the most important seaports of Russia, ranking, by reason of its population and its foreign trade, after Petrograd, Moscow, and Warsaw. Since it was founded in 1794, near the ruins of a Turkish fort that fell into Russian hands in 1789, it has rapidly become the intellectual and commercial capital of what is called New Russia. It is the principal export town for the extensive grain-growing districts of South Russia, the See of an Archbishop of the Greek Orthodox Church, the center of a fine university, and the headquarters of the Seventh Army Corps.

The port lies on the shore of the Black Sea, about midway between the estuaries of the Dniester and the Dnieper, 967 miles from Moscow and 381 from Kieff. The city is built facing the sea, on low cliffs, seamed with deep ravines and hollowed out by galleries in the soft rock, in which thousands of the poorest inhabitants live. But above this are fine broad tree-lined streets and squares bordered with handsome public buildings and mansions in the Italian style, and good shops. Besides the cathedral, there are dozens of other churches, a fine opera house, and the Palais Royal, which, with its gardens and park, is a favorite place of resort. A magnificent flight of granite steps leads from the Richelieu monument to the harbors, and the shore is lined with granaries, some of which look like palaces.

The bay of Odessa, which has an area of fourteen square miles, was a dangerous anchorage, on account of its exposure to easterly winds, until the harbors within it, six in number, protected by moles and breakwaters, were constructed. Besides these, there are the harbor of the Russian Company for Navigation and Commerce, and the petroleum harbor. These harbors are frozen for a few days only in winter, but navigation is rarely interrupted for more than sixteen days at the most.

The population has steadily increased from 3,150 in 1796 to about 450,000 at the present day. The total exports were valued some time ago at about $55,000,000 annually and the imports at about $40,000,000, about 8½ per cent of all the imports into Russia. Grain, and particularly wheat, is the chief article of export. Petroleum is also an important export at the present time. The principal imports are raw cotton, iron, agricultural machinery, coal, chemicals, jute, copra, and lead. Well over 1,200 vessels, of some 1,750,000 tonnage, enter the port every year, and of these about 700, with a tonnage of 1,250,000, are British.—*The Daily Telegraph.*

Translucent Glass Bricks

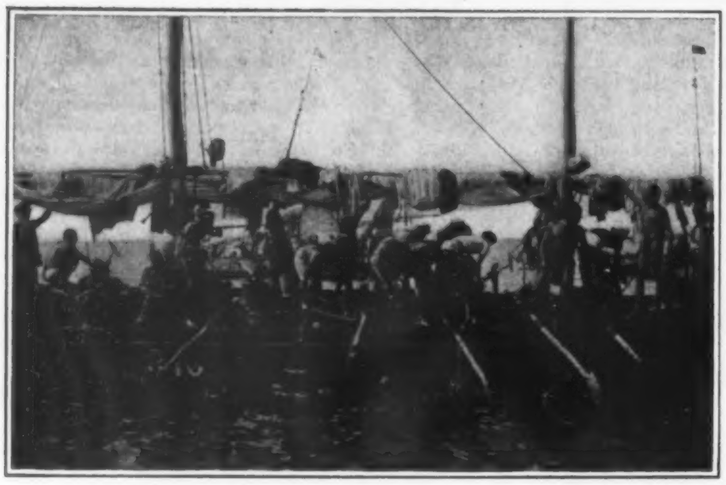
At a recent meeting of the Illuminating Engineers Society one of the speakers made a novel but eminently practical suggestion in regard to the interior lighting of buildings. His remarks were as follows: "Not long since a resident owner called my attention to the fact that the front rooms of his home were in daytime the darkest ones in the house, notwithstanding the fact that these rooms were the most used and the most important. The darkness was caused there—and in fact will be caused in any average residence—by the shielding effect of a large porch, and overhanging eaves. This is a very common condition, and it seems peculiar to me that use has not been made of prism plate glass, or ribbed sheets, in the form of skylights set in the veranda roof, to direct the daylight against the face of the building and into the windows. Glass with a smooth upper side, and with prisms on its lower face, parallel to the building, would direct considerably more light into these front rooms than is found at present. Going a little further, it seems reasonable to me that use could be made of translucent glass brick or glass blocks in the actual construction of a building. Such blocks could readily be made of a glass of pleasing color tints, impervious to weather, and it is conceivable how many beautiful effects could be worked into spaces between pilasters, around domes, friezes, etc. Many architects do not want to have the exterior of a building made characterless by the use of many windows. Glass brick, tinted the color of stone, would offer a solution of such a problem."

Preventing Soil Erosion

Soil erosion is doing immense damage constantly and few people know how to apply preventive measures. In the annual report of the Bureau of Soils of the Department of Agriculture a simple method of handling one class of erosions is described. This is the case where the soil is being washed away in gullies, and the remedy is to build a dam across the incipient gulley through which a sewer pipe is passed, connecting with an upright pipe situated at the upper side of the dam. The hollow formed by the dam will fill with water in flood conditions until the top of the upright pipe is reached, when the excess of water runs off quietly into the next field or into another impounding space below. The cutting current of the draining water is stopped and the sediment carried by it settles above the dam, thus tending to repair the damage previously done. A suitable tile drain located under the dam will dispose of the water impounded below the opening of the upright pipe.

A Valuable Sub-Tropical Hay Grass

At the third International Congress of Tropical Agriculture attention was called to a valuable species of grass that has been introduced into South Africa with remarkable success. This is known as Teff (*Eragrostis abassinica*) and is an annual hay grass, particularly suitable as a summer catch-crop, and a smother-crop for weeds, owing to its rapid growth when weather conditions are at all favorable. It gives a heavy yield of hay of fine quality and high nutritive value, more nearly resembling English meadow hay than any other hay grass grown in South Africa. If sown with the early spring rains it has been possible to cut three crops of hay in the season, giving 2½ to 3 tons per acre, and to obtain autumn grazing from the aftermath. The introduction of Teff grass into South Africa has raised many small farmers struggling for a living to positions of comparative comfort and independence. They are unanimously agreed that this introduction alone has repaid over and over again the whole cost of the Division of Botany of the Department of Agriculture from its inception to date.



Native pearl fishers at work on a bank.

An inspector about to descend in a diving dress.

The Pearl Fisheries of Ceylon

How the Pearl-Bearing Oysters are Gathered by Naked Divers

By R. I. Geare

THE finding of large and valuable pearls has been a matter of deep interest to mankind for centuries. The Ceylonese fisheries, which had been operated at intervals since long before the Christian era, are probably the most ancient of these fisheries. The most perfect pearl ever discovered in that region was bought in 1633 by the Shah of Persia for about $51,000 from an Arab, who brought it from Catifa, a fishery opposite Bhareen in the Persian Gulf. Another magnificent pearl—a black specimen—was sold to a New York firm not many years ago for about $25,000.

The true pearl oyster, known scientifically as *Meleagrina margaratifera*, and belonging to the family Aviculidæ, differs from the edible oyster in having a small "foot" and anterior adductor muscle, a well-developed byssus gland, which secretes a bunch of fibers by which the animal is attached to rock or stone, and a thick "mother-of-pearl" layer to the shell.

The Ceylon fisheries are operated on banks covering an extensive area off the north coast of the island. Tradition has it that King Solomon obtained some of his wonderful pearls from the Ceylon banks, and even the pearls which Cleopatra dissolved and drank are credited with a Ceylonese origin.

The banks most famous in past times lie close to the shore in the Gulf of Mannar, near a place called Marichchukkaddi.

At one time, when Ceylon was under the Tamil power, the pearl fisheries were conducted frequently and successfully. They were watched over by a Tamil princess, who was carried to the end of the Karaittiva Point, and there enthroned until the fishery was over, to prevent robbery on the part of the divers.

One of the earliest mentions of pearl fisheries in Ceylon occurs in the Rajavali chronicle (306 B. C.), where they are spoken of as being located near Colombo; but they were unfortunately destroyed by an inundation from the sea.

During the Portuguese control of the island of Ceylon there is no record of any pearl fishing, but during the 140 years it was occupied by the Dutch there were at least four important fisheries between 1732 and 1749, in the course of which probably not less than a million dollars' worth of pearls were secured.

During the British occupancy of Ceylon, which still exists, the pearl banks have been under the inspectorship of the "Master Attendant of the port of Colombo," while the government agent of the Northern Province acts as "Official Superintendent."

The oyster beds are formed by an amalgam of coarse granite sand and old oyster shells cemented together with coral lime. Here there is but little movement of the sand, so that the oysters remain easily accessible; but away from the beds the sand, which is loose, is formed into huge waves, which have the effect of covering up and destroying the oysters immediately.

The life of a Ceylon pearl oyster is not more than eight years, and from about its third year it seems to be most productive, both in the number and size of pearls. As a matter of fact very few 3-year oysters contain valuable pearls, but when a bed of oysters is fished just as they are dying off with old age the pearls obtained are liable to be many and large.

True pearls, which are, in fact, the result of a disease sometimes brought about by the introduction into the shell of some foreign body, such as a grain of sand, an undeveloped egg, a parasite, etc., are formed in the tissue of the oyster, and when they reach such a size as to cause great discomfort to the oyster the latter either dies or forces the pearl toward the opening between the valves, where it is retained by an absolutely transparent substance or skin, and here it increases in growth.

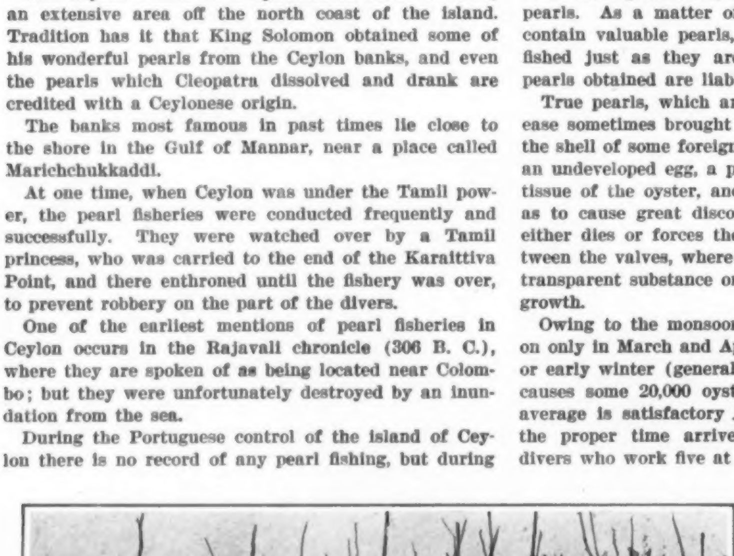
Owing to the monsoons pearl fishing can be carried on only in March and April. During the preceding fall or early winter (generally in November), the inspector causes some 20,000 oysters to be "lifted," and if the average is satisfactory the fishery is ordered. When the proper time arrives the boats, each containing divers who work five at a time, are rowed or sailed to the banks. Each pair of divers has an attendant known as a "manduck." The boat also contains a "tindal," or representative of the owner of the boat, and a "peon," who represents the interests of the government.

The divers are allowed for payment one third of the oysters taken, while the government auctions off the remainder on the beach the same evening they are caught. The oysters are then placed by the purchasers in "kottus," or inclosures, and are allowed to rot for eight or ten days in some receptacle—often a wooden canoe—which is covered over to shade the oysters from the sun, but permits flies to obtain free access, as they assist in the process of rotting. Later, the whole mass is washed with clean water, the shells, stones and byssus (or green, string-like substance by which the oyster attaches itself to the rock) are picked out, and the residue placed on long strips of black calico to dry. During the drying process the whole mass is picked over and over again and carefully scrutinized for the smallest pearls.

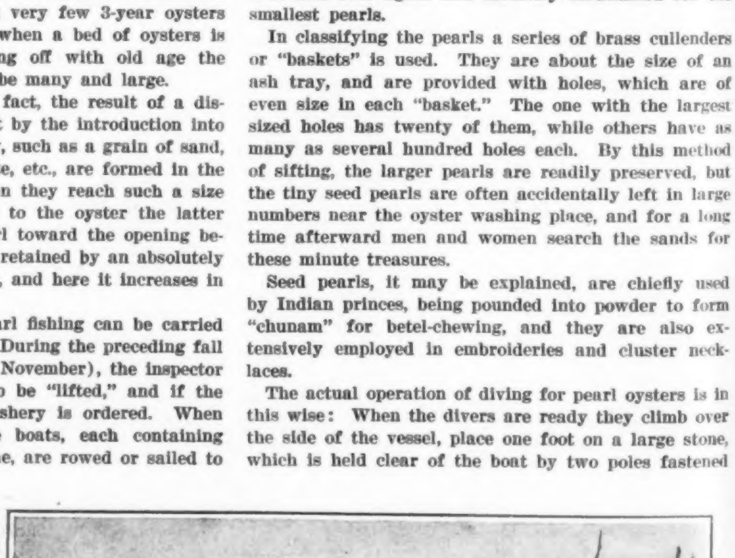
In classifying the pearls a series of brass cullenders or "baskets" is used. They are about the size of an ash tray, and are provided with holes, which are of even size in each "basket." The one with the largest sized holes has twenty of them, while others have as many as several hundred holes each. By this method of sifting, the larger pearls are readily preserved, but the tiny seed pearls are often accidentally left in large numbers near the oyster washing place, and for a long time afterward men and women search the sands for these minute treasures.

Seed pearls, it may be explained, are chiefly used by Indian princes, being pounded into powder to form "chunam" for betel-chewing, and they are also extensively employed in embroideries and cluster necklaces.

The actual operation of diving for pearl oysters is in this wise: When the divers are ready they climb over the side of the vessel, place one foot on a large stone, which is held clear of the boat by two poles fastened



Pearl oysters in a Kottu, or rotting inclosure.



Pearl fishers landing their catch.

at right angles over the boat's side, and by a third pole which lies parallel to the length of the vessel and is lashed to each end of the other two.

Grasping the rope which is attached to this stone and hitching over his arm the rope attached to the basket in which the diver places his catch, he takes a deep breath, closing his nostrils with his free hand, and slightly raising himself—to add impetus to his descent—gives the signal to the "manduck" to release the rope to which the stone is fastened. On reaching the bottom the diver lets go of the stone, which is then hauled up, so as to be ready for the next descent, and, swimming on the bottom, grasps all the oysters within his reach. When his breath is nearly exhausted, the diver signals to be pulled up with his basket and rises partly by his own initiative. Occasionally the divers are severely stung by jellyfishes, and sometimes they stay down too long and, actuated by avarice or overestimating their own strength, are brought up dead. When collecting the oysters they seem to float on the bottom of the sea, with backs arched and heels above their heads, while their long hair waves in a graceful manner and is upheld by the action of the water. A Tamil diver remains below from 50 to 60 seconds, but an Arab can stay down from 80 to 90 seconds.

Diving bells were imported into Ceylon by Sir Edwards Barnes in 1825, but they nor Europeans in a diving dress can compete with the naked diver.

The catch of one boat for a successful week's fishing should total about 180,000 oysters.

X-Rays and Crystalline Structure*

Discoveries That Assist in the Understanding of Theories of X-Rays and Light

By Prof. William H. Bragg

Two years have gone by since Dr. Laue made his surprising discovery of the interference effects accompanying the passage of X-rays through crystals. The pioneer experiment has opened the way for many others, and a very large amount of work, theoretical and practical, has now been done. As the preliminary exploration of the new country has proceeded, our first estimate of its resources has grown continuously; we have learned many things which help us to a better understanding of phenomena already familiar, and we have seen avenues of inquiry open out before us which as yet there has been little time to follow. The work is full of opportunities for exact quantitative measurements, where precision is sure to bring its due reward. There is enough work in sight to absorb the energies of many experimenters, and there is sure to be far more than we can see. When we consider the wideness of the new field, the quality and quantity of the work to be done in it, and the importance of the issues, we are scarcely guilty of over-statement if we say that Laue's experiment has led to the development of a new science. The experiment itself, to put it very briefly, constitutes a proof that X-rays consist of extremely short ether waves. In order to appreciate the value of this demonstration, we must bear in mind the present conditions of our knowledge of the laws of radiation in general. Let us consider very shortly how the whole matter stood when the new work was begun.

When X-rays were first discovered eighteen years ago it was soon pointed out that they might consist of electro-magnetic disturbance of the ether analogous to those supposed to constitute light. It was true that the new rays seemed to be incapable of reflection, refraction, diffraction and interference, which were familiar optical phenomena. But it was pointed out by Schuster[1] that these defects could be explained as natural consequences of an extremely small wave-length. The positive evidence consisted mainly in the knowledge that the impact of the electrons on the anti-cathode of the X-ray bulb ought to be the occasion of electro-magnetic waves of some sort, and in the discovery by Barkla that the X-rays could be polarized, which last is a property also of light.

As experimental evidence accumulated, a number of results were found which the electro-magnetic theory was unable to explain, at least in a direct and simple manner. They were mainly concerned with the transference of energy from place to place. In some way or other the swiftly moving electron of the X-ray bulb transfers its energy to the X-ray, and the X-ray in its turn communicates approximately the same quantity of energy to the electron which originates from matter lying in the track of the X-ray, and which is apparently the direct cause of all X-ray effects. Experiment seemed to indicate that X-ray energy traveled as a stream of separate entities or quanta, the energy of the quantum differing according to the quality of the X-ray. It seemed at one time as if it might be the simplest plan to deny the identity in nature of X-rays and light, to describe the former as a corpuscular radiation and the latter as a wave motion. Otherwise, it seemed that the electro-magnetic hypothesis would be torn to pieces in the effort to hold all the facts together.

But it appeared on a close examination of light phenomena also, though in much less obvious fashion, that the very same effects occurred which in the case of X-rays were so difficult to explain from an orthodox point of view. In the end it became less difficult to deny the completeness of the orthodox theory than the identity in nature of light and X-rays. Modern work on the distribution of energy in the spectrum, and the dependence of specific heat upon temperature, has also led independently to the same point of view. It has been urged with great force by Planck, Einstein, and others that radiated energy is actually transferred in definite units or quanta, and not continuously; as if we had to conceive of atoms of energy as well as of atoms of matter. Let it be admitted at once that the quantum theory and the orthodox theory appear to stand in irreconcilable opposition. Each by itself correlates great series of facts; but they do not correlate the same series. In some way or other the greater theory must be found, of which each is a partial expression.

The new discovery does not solve our difficulty at once, but it does two very important things. In the first place, it shows that the X-rays and light are identical in nature; in fact, it removes every difference except in respect to wave-length. The question as to the exact place where the difficulty lies is decided for us; we are set the task of discovering how a continuous wave motion, in a continuous medium, can be reconciled with discontinuous transferences of radiation energy. Some solution there must be to this problem. The second important thing is that the new methods will surely help us on the way to find that solution. We can now examine the X-rays as critically as we have been able to study light, by means of the spectrometer. The wave-length of the X-ray has emerged as a measurable quantity. The complete range of electro-magnetic radiations now lies before us. At one end are the long waves of wireless telegraphy, in the middle are first the waves of the infra-red detected by their heating effects, then the light waves, and then the short waves of the ultra-violet. At the other end are the extremely short waves that belong to X-radiation. In the comparative study of the properties of radiation over this very wide range we must surely find the answer to the greatest question of modern physics.

So much for the general question. Let us now consider the procedure of the new investigations, and afterwards one or two applications to special lines of inquiry.

The experiment due to Laue and his collaborators Friedrich and Knipping has already been described in this lecture room and is now well known. A fine pencil of X-rays passes through a thin crystal slip and impresses itself on a photographic plate. Round the central spot are found a large number of other spots, arranged in a symmetrical fashion, their arrangement clearly depending on the crystal structure. Laue had anticipated some such effect as the result of diffraction by the atoms of the crystal. His mathematical analysis is too complicated to be described now, and indeed it is not in any circumstances easy to handle. It will be better to pass on at once to a very simple method of apprehending the effect which was put forward soon after the publication of Laue's first results. I must run the risk of seeming to be partial if I point out the importance of this advance, which was made by my son W. Lawrence Bragg. All the recent investigations of X-ray spectra and the examination of crystal structure and of molecular motions which have been carried out since then have been rendered possible by the easy grasp of the subject which resulted from the simpler conception.

Let us imagine that a succession of waves constituting X-radiation falls upon a plane containing atoms, and that each atom is the cause of a secondary wavelet. In a well known manner, the secondary wavelets link themselves together and form a reflected wave. Just so a sound wave may be reflected by a row of palings, and very short sound waves by the fibers of a sheet of muslin.

Suppose a second plane of atoms to lie behind the first and to be parallel to it. The primary wave, weakened somewhat by passing through the first plane, is again partially reflected by the second. When the two reflected pencils join it will be of great importance whether they fit crest to crest and hollow to hollow, or whether they tend to destroy each other's effect. If more reflecting planes are supposed, the importance of a good fit becomes greater and greater. If the number is very large, then, as happens in many parallel cases in optics, the reflected waves practically annul each other unless the fit is perfect.

It is easily seen that the question of fit depends on how much distance a wave reflected at one plane loses in comparison with the wave which was reflected at the preceding plane: the fit will be perfect if the loss amounts to one, two, three, or more wave-lengths exactly. In its turn the distance lost depends on the spacing of the planes, that is to say, the distance from plane to plane, on the wave-length, and on the angle at which the rays meet the set of planes.

The question is formally not a new one. Many years ago Lord Rayleigh discussed it in this room, illustrating his point by aid of a set of muslin sheets stretched on parallel frames. The short sound waves of a high pitched bird call were reflected from the set of frames and affected a sensitive flame; and he showed how the spacing of the planes must be carefully adjusted to the proper value in relation to the length of wave and the angle of incidence. Rayleigh used the illustration to explain the beautiful color of chlorate of potash crystals. He ascribed them to the reflection of light by a series of parallel and regularly spaced twinning planes within the crystal, the distance between successive planes bearing, roughly, the same proportion to the length of the reflected wave of light at the distance between the muslin sheets to the length of the wave of sound.

Our present phenomenon is exactly the same thing on a minute scale; thousands of times smaller than in the case of light; and many millions of times smaller than in the case of sound.

By the kindness of Prof. R. W. Wood I am able to show you some fine examples of the chlorate of potash crystals. If white light is allowed to fall upon one of them, the whole of it is not reflected. Only that part is reflected which has a definite wave-length or something very near to it, and the reflected ray is therefore highly colored. The wave-length is defined by the relation already referred to. If the angle of incidence is altered, the wave-length which can be reflected is altered, and so the color changes.

It is not difficult to see the analogy between these cases and the reflection of X-rays by a crystal. Suppose, for example, that a pencil of homogeneous X-rays meets the cube face of such a crystal as rocksalt. The atoms of the crystal can be taken to be arranged in planes parallel to that face, and regularly spaced. If the rays meet the face at the proper angle, and only at the proper angle, there is a reflected pencil. It is to be remembered that the reflection is caused by the joint action of a series of planes, which, in this case, are parallel to the face; it is not a reflection by the face itself. The face need not even be cut truly; it may be unpolished or deliberately roughened. The reflection takes place in the body of the crystal, and the condition of the surface is of little account.

The allotment of the atoms to a series of planes parallel to the surface is not, of course, the only one possible. For example, in the case of a cubic crystal, parallel planes containing all the atoms of the crystal may also be drawn perpendicular to a face diagonal of the cube, or to a cube diagonal, or in many other ways. We may cut the crystal so as to show a face parallel to any series, and then place the crystal so that reflection occurs, but the angle of incidence will be different in each case since the spacings are different. It is not necessary to cut the crystal except for convenience. If wave-length, spacing, and angle between ray and plane are rightly adjusted to each other, reflection will take place in the crystal independently of any surface arrangement.

This is the "reflection" method of explaining the Laue photograph. W. L. Bragg showed in the first place that it was legitimate, and in the second, that it was able to explain in the position of all the spots which Laue found upon his photographs. The different spots are

*Read before the Royal Institution of Great Britain, June 5, 1914.

[1] Nature, January 23rd, 1896.

reflections in different series of planes which may be drawn to contain the atoms of the crystal. The simpler conception led at once to a simpler procedure. It led to the construction of the X-ray spectrometer, which resembles an ordinary spectrometer in general form, except that the grating of prism is replaced by a crystal and the telescope by an ionization chamber and an electroscope. In use a fine pencil of X-rays is directed upon the crystal, which is steadily turned until a reflection leaps out; and the angle of reflection is then measured. If we use different crystals or different faces of the same crystal, but keep the rays the same, we can compare the geometrical spacings of the various sets of planes. If we use the same crystals always, but vary the source of X-rays, we can analyze the latter, measuring the relative wave-lengths of the various constituents of the radiation.

We have thus acquired a double power: (1) We can compare the intervals of spacing of the atoms of a crystal or of different crystals, along various directions within the crystal; in this way we can arrive at the structure of the crystal. (2) We can analyze the radiation of an X-ray bulb; in fact, we are in the same position as we should have been in respect to light if our only means of analyzing light had been the use of colored glasses, and we had then been presented with a spectrometer or some other means of measuring wave-length exactly.

We now come to a critical point. If we knew the exact spacings of the planes of some one crystal, we could now by comparison find the spacing of all other crystals, and measure the wave-length of all X-radiations; or if we knew the exact value of some one wave-length, we could find by comparison the values of all other wave-lengths and determine the spacings of all crystals. But as yet we have no absolute value either of wave-length or of spacings.

The difficulty appears to have been overcome by W. L. Bragg's comparison of the reflecting effect in the case of rocksalt or sodium chloride, and sylvine or potassium chloride. These two crystals are known to be "isomorphous"; they must possess similar arrangements of atoms. Yet they display a striking difference both in the Laue photograph and on the spectrometer. The reflections from the various series of planes of the latter crystal show spacings consonant with an arrangement in the simplest cubical array, of which the smallest element is a cube at each corner of which is placed the same group, a single atom or molecule, or group of atoms or molecules. In the case of rocksalt the indications are that the crystal possesses a structure intermediate between the very simple arrangement just described and one in which the smallest element is a cube having a similar group of atoms or molecules at every corner and at the middle point of each face. The arrangement is called by crystallographers the face centered cube. The substitution of the sodium for the potassium atom must transform one arrangement into the other. This can be done in the following way, if we accept various indications that atoms of equal weight are to be treated as equivalent. Imagine an elementary cube of the crystal pattern to have an atom of chlorine at every corner and in the middle of each face, and an atom of sodium or potassium, as the case may be, at the middle point of each edge and at the center of the cube. We have now an arrangement which fits the facts exactly. The weights of the potassium and chlorine atoms are so nearly the same as to be practically equivalent, and when they are considered to be so the arrangement becomes the simple cube of sylvine. But when the lighter sodium replaces the potassium, as in rocksalt, the arrangement is on its way to be that of the face centered cube, and would actually become so were the weight of the sodium atoms negligible in comparison with those of chlorine. Of course the same result would follow were two or three, or any number of atoms of each sort to take the place of the single atom, provided the same increase were made in the number of atoms of both sorts. We might even imagine two sorts of groups of chlorine and metal atoms, one containing a preponderance of the former, the other of the latter, but so that two groups, one of each kind, contain between them the same proportion of chlorine and metal as the crystal does. We must merely have two groups which differ in weight in the case of rocksalt, and are approximately equal in the case of sylvine. But it was best to take the simplest supposition at the outset; and now the evidence that the right arrangement has been chosen is growing as fresh crystals are measured. For it turns out that in all crystals so far investigated the number of atoms at each point must always be the same. Why, then, should it be more than one? Or, in other words, if atoms are always found in groups of a certain number, ought not that group to be called the atom?

As soon as the structure of a crystal has been found we can at once find by simple arithmetic the scale on which it is built. For we know from other sources the weight of individual atoms, and we know the total weight of the atoms in a cubic centimeter of the crystal. In this way we find that the nearest distance between two atoms in rocksalt is 2.81×10^{-8} centimeters, which distance is also the spacing of the planes parallel to a cube face. From a knowledge of this quantity the length of any X-ray wave can be calculated at once as soon as the angle of its reflection by the cube face has been measured. In other words, the spectrometer has now become a means of measuring the length of waves of any X-radiation, and the actual spacings of the atoms of any crystal.

From this point the work branches out in several directions. It will not be possible to give more than one or two illustrations of the progress along each branch.

Let us first take up the most interesting and important question of the "characteristic" X-rays. It is known that every substance when bombarded by electrons of sufficiently high velocity emits X-rays of a quality characteristic of the substance. The interest of this comparison lies in the fact that it displays the most fundamental properties of the atom. The rays which each atom emits are characteristic of its very innermost structure. The physical conditions of the atoms of a substance and their chemical associations are largely matters of the exterior; but the X-rays come from the interior of the atoms and give us information of an intimate kind. What we find is marked by all the simplicity we should expect to be associated with something so fundamental.

All the substances of atomic weight between about 30 and 120 give two strongly defined "lines"; that is to say, there are found among the general heterogeneous radiation two intense almost homogeneous sets of waves. For instance, rhodium gives two pencils of wave-lengths, approximately equal to 0.61×10^{-8} centimeters and 0.54×10^{-8} centimeters, respectively. More exactly, the former of these is a close doublet, having wave-lengths 0.619×10^{-8} and 0.614×10^{-8}. The wave-lengths of palladium are nearly 0.58×10^{-8} and 0.51×10^{-8}; nickel, 1.66×10^{-8} and 1.50×10^{-8}. Lately Moseley has made a comparative study of the spectra of the great majority of the known elements, and has shown that the two-line spectrum is characteristic of all the substances whose atomic weights range from that of aluminium, 27, to that of silver, 108. These X-rays constitute, there is no doubt whatever, the characteristic rays which Barkla long ago showed to be emitted by this series of substances.

Now comes a very interesting point. When Moseley sets the increasing atomic weights against the corresponding decreasing wave-lengths, the changes do not run exactly parallel with each other. But if the wave-lengths are compared with a series of natural numbers everything runs smoothly. In fact, it is obvious that the steady decrease in the wave-length as we pass from atom to atom of the series in the periodic table implies that some fundamental element of atomic structure is altering by equal steps. There is excellent reason to believe that the change consists in successive additions of the unit electric charge to the nucleus of the atom. We are led to think of the magnitude of the nucleus of any element as being simply proportional to the number indicating the place of the element in the periodic table, hydrogen having a nuclear change of one unit, helium two, and so on. The atomic weights of the successive elements do not increase in an orderly way; they mount by steps of about two, but not very regularly, and sometimes they seem absolutely to get into the wrong order. For example, nickel has an atomic weight of 58.7, whereas certain chemical properties and still more its behavior in experiments on radio-activity indicate that it should lie between cobalt (59) and copper (63.6). But the wave-lengths, which are now our means of comparison, diminish with absolute steadiness in the order cobalt, nickel, copper. Plainly, the atomic number is a more fundamental index of quality than the atomic weight.

It is very interesting to find, in the series arranged in this way, four, and only four, gaps which remain to be filled by elements yet undiscovered.

Let us now glance at another and most important side of the recent work, the determination of crystalline structure. We have already referred to the case of the rocksalt series, but we may look at it a little more closely in order to show the procedure of crystal analysis.

The reflection of a pencil of homogeneous rays by a set of crystalline planes occurs, as already said, at a series of angles regularly increasing; giving, as we say, spectra of the first, second, third orders, and so on. When the planes are all exactly alike and equally spaced the intensities of the spectra decrease rapidly as we proceed to higher orders, according to a law not yet fully explained. This is, for example, the case with the three most important sets of planes of sylvine, those perpendicular to the cube edge, the face diagonal, and the cube diagonal, respectively. An examination of the arrangement of the atoms in the simple cubical array of sylvine shows that for all these sets the planes are evenly spaced and similar to each other. It is to be remembered that the potassium atom and the chlorine atom are so nearly equal in weight that they may be considered effectively equal. In the case of rocksalt, the same may be said of the first two sets of planes, but not of the third. The planes perpendicular to the cube diagonal are all equally spaced, but they are not all of equal effect. They contain, alternately, chlorine atoms (atomic weight 35.5) only and sodium atoms (atomic weight 23) only. The effect of this irregularity on the intensities of the spectra of different orders is to enhance the second, fourth, and so on in comparison with the first, third, and fifth. The analogous effect in the case of the light is given by a grating in which the lines are alternately light and heavy. A grating specially ruled for us at the National Physical Laboratory shows this effect very well. This difference between rocksalt and sylvine and its explanation in this way constituted an important link in W. Lawrence Bragg's argument as to their structure.

When, therefore, we are observing the reflections in the different faces of a crystal in order to obtain data for the determination of its structure, we have more than the values of the angles of reflection to help us; we have also variations of the relative intensities of the spectra. In the case just described we have an example of the effect produced by want of similarity between the planes, which are, however, uniformly spaced.

In the diamond, on the other hand, we have an example of an effect due to a peculiar arrangement of planes which are otherwise similar. The diamond crystallizes in the form of a tetrahedron. When any of the four faces of such a figure is used to reflect X-rays, it is found that the second order spectrum is missing. The analogous optical effect can be obtained by ruling a grating so that, as compared with a regular grating of the usual kind, the first and second, fifth and sixth, ninth and tenth alone are drawn. To put it another way, two are drawn, two left out, two drawn, two left out, and so on. The National Physical Laboratory has ruled a special grating of this kind also for us, and the effect is obvious. The corresponding inference in the case of the diamond is that the planes parallel to any tetrahedral face are spaced in the same way as the lines of the grating. Every plane is three times as far from its neighbor on one side as from its neighbor on the other. There is only one way to arrange the carbon atoms of the crystal so that this may be true. Every atom is at the center of a regular tetrahedron composed of its four nearest neighbors, an arrangement best realized by the aid of a model. It is a beautifully simple and uniform arrangement, and it is no matter of surprise that the symmetry of the diamond is of so high an order. Perhaps we may see also, in the perfect symmetry and consequent effectiveness of the forces which bind each atom to its place, an explanation of the hardness of the crystal.

Here, then, we have an example of the way in which peculiarities of spacing can be detected. There are other crystals in which want of uniformity both in the spacings and in the effective value of the planes combine to give cases still more complicated. Of these are iron pyrites, calcite, quartz and many others. It would take too long to explain in detail the method by which the structures of a large number of crystals have already been determined. Yet the work done already is only a fragment of the whole, and it will take, no doubt, many years, even though our methods improve as we go on, before the structures of the most complicated crystals are satisfactorily determined.

On this side, then, we see the beginning of a new crystallography, which, though it draws freely on the knowledge of the old, yet builds on a firmer foundation since it concerns itself with the actual arrangement of the atoms rather than the outward form of the crystal itself. We can compare with the internal arrangements we have now discovered the external forms which crystals assume in growth, and the modes in which they tend to come apart under the action of solvents and other agents. By showing how atoms arrange and disarrange themselves under innumerable variations of circumstances we must gain knowledge of the nature and play of the forces that bind the atoms together.

There is yet a third direction in which inquiry may be made, though as yet we are only at the beginning of it. In the section just considered we have thought of the atoms as at rest. But they are actually in motion, and the position of an atom to which we have referred so frequently must be an average position about which it is in constant movement. Since the atoms are never exactly in their places, the precision of the joint action on which the reflection effect depends suffers materially. The effect is greater the higher the order of the spectrum. When the crystal under examination is contained within a suitable electric furnace and the atoms vibrate more violently through the rise of temperature

the intensities of all orders diminish, but those of higher order much more than those of lower. The effect was foreseen by the Dutch physicist Debije, and the amount of it was actually calculated by him on certain assumptions. I have found experimental results in general accord with this formula. In passing it may be mentioned that as the crystal expands with rise of temperature the spacing between the planes increases and the angles of reflection diminish, an effect readily observed in practice.

This part of the work gives information respecting the movements of the atoms from their places, the preceding respecting their average positions. It is sure, like the other, to be of much assistance in the inquiry as to atomic and molecular forces, and as to the degree to which thermal energy is locked up in the atomic motions.

This brief sketch of the progress of the new science in certain directions is all that is possible in the short time of a single lecture; but it may serve to give some idea of its fascination and possibilities.

The Geology of the Yellowstone National Park

A Striking Topographical Structure and a Complete Geological Problem

By Carl Hawes Butman

In the year 1872 Congress set aside a tract of land in the the northwest corner of Wyoming for the benefit of mankind and the preservation of the natural wonders of the country. This became known as the Yellowstone National Park, and was the first tract thus set aside for this purpose. It includes some 3,340 square miles, but in relation to the whole of Wyoming it appears on the map as a misplaced postage stamp, which, like many stamps, overlaps the letter by extending a little way into both Montana and Idaho. Following the precedent thus established 40 years ago, Congress has since established eleven smaller parks in various places where the public might find recreation and where the wonders of nature therein might be preserved from desecration.

From the point of view of the geologist Yellowstone Park is in a way unique. Its central plateau, with the adjacent mountains, presents a sharply defined region contrasting with the remainder of the northern Rocky Mountains; a striking piece of topographical structure and a complete geological problem. The central portion consists of a broad, elevated irregular plateau of volcanic origin, some 40 miles square, extending between 7,000 and 8,500 feet above sea level, and surrounded on the north, northwest, south, east and northeast by mountain ranges, the peaks and highest points of which extend upward like a gigantic wall for 2,000 to 4,000 feet more.

Just south of the park the Tetons, the highest and grandest peaks in the northern Rocky Mountains, stand out prominently, but only the outlying spurs come within the limits of the park proper. These mountains are composed mostly of coarse crystalline gneisses and shists, probably of Archean age, abutted on the northern spurs by upturned Paleozoic strata.

On the eastern edge of the park the Absaroka Range stretches from the north to the south, where it connects with the northern end of the Wind River Range. For more than 80 miles this range presents a bold unbroken barrier along the eastern side of the park, its highest peaks towering 10,000 or 11,000 feet aloft.

At the northeastern corner of the park an irregular mass of mountains joins the Absarokas with the Snowy Range, which forms the northern boundary of the reservation, with its rough, snow-covered elevations. The rocks of the southern slopes of the Snowy Range, which extend into the park, are composed mainly of granite, gneiss and shist, while their sedimentary beds belong to the pre-Cambrian series.

Enclosing the park on the northwestern corner lies the Gallatin Range, separated from the Snowy Range on the east by the valley of the Yellowstone River. It is a beautiful mountain range, presenting diversified forms, as well as varied geological problems. Its crowning glory, Electric Peak, 11,100 feet in height, and incidentally the tallest peak in this region, gets its name from the magnetic disturbances discovered by the first explorers to carry surveying instruments up its slopes. An important part of the Gallatin Range is formed of Archean gneisses covered with a series of limestone, sandstone, and shale beds, both of the Paleozoic and Mesozoic eras, representing Cambrian, Silurian, Devonian, Carboniferous, Triassic, Jurassic and Cretaceous periods. Large masses of intrusive rocks, closely allied with the sedimentary beds, have taken an important part in creating the present structural features of this range. They are of the andesitic type and cover a broad range of mineral composition, including pyroxene, hornblende, and hornblende-mica.

The general region of the park was at one time subjected to severe dynamic action which affected all the ranges at about the same time, and probably occurred during the latter part of the Cretaceous period, although the work of mountain building seems to have continued into the Middle Tertiary period. During the latter period the site of the park was torn up by volcanic action, which continued to a lesser extent through the Pliocene and into the Quaternary periods. All such action has long since ceased, but the volcanic rocks remain, offering much interesting information. They comprise three groups which succeeded each other: andesites with basalts, rhyolites, and basalts. Probably the andesitic eruptions continued for the greatest period of time, since there are evidences of plant life buried under 2,000 feet of volcanic material.

In Tertiary times there is supposed to have existed a large volcano, named the Sherman, and of which Mount Washburn is a more recent crater, the bursting forth of which caused the destruction of the original crater of the older volcano. Recent eruptions and erosions have so destroyed the early volcanic flows that it is difficult to identify the ancient andesitic lava which was afterwards submerged by immense quantities of rhyolite to a thickness of nearly 8,500 feet. In fact, nothing else remains to be seen but rhyolitic rock, except the mineral spring deposits, and the remains of the early crater rim on Mount Washburn. Another source of the rhyolite flows is supposed to have been Mount Sheridan in the southern part of the reservation, which towers to a height of 10,385 feet and offers a remarkable view of the volcanic region stretching across the park from east to west. The deep gorges of the Yellowstone, Gibbon and Madison Rivers have not worn through this tremendous thickness of rock, and only in the Grand Canyon of the Yellowstone are the ancient andesitic breccias exposed beneath the rhyolites, while nowhere are the sedimentary beds revealed. The central plateau includes the finest examples of structural forms, crystallization, and mode of origin of acidic lavas, varying from a nearly holocrystalline rock to pure volcanic glass, that can be found in the world.

Following the rhyolite eruption there came a period of faulting and displacement, succeeded by eruptions of basalt, which, however, deposited but a thin layer over the rhyolite and did practically nothing to change the physical aspect of the country. The glacial action which soon occurred, nevertheless, carved out the early drainage channels, cut gorges into the rhyolite lava, and shaped the two volcanoes into their present form. Traces of the ancient glaciers are to be found nearly everywhere, especially in the several mountain ranges, while in the Tetons there exist to-day glaciers characteristic of the ancient grand system which extended over the entire plateau. Erosion continued the work of the glaciers in remodeling the park surface, and this action has carved, since that time, the deep gorges of the Madison, Gibbon and Yellowstone rivers, veritable canyons, cut to a depth of nearly 1,500 feet and several miles in length.

Much evidence of the great glacial action is still at hand; the valley of the lower Yellowstone River is strewn with rocks brought by the glacier from both the east and west borders of the park. One example of the tremendous force of the ice floes of the early times is a great granite bowlder (about 20 feet in diameter) brought down and deposited on the brink of the Grand Canyon. It is completely isolated from its fellows and quite 30 miles from where it must have been transported. The glacial action took place since the travertine deposits of the hot springs were formed. This is shown especially at Terrace Mountain near the Mammoth Hot Springs, where the travertine, covering the rhyolite plateau, is strewn with glacial bowlders brought from the Gallatin Range some 15 miles away, indicating that the travertine is older than the glacier.

Probably the most interesting feature of the park today is the series of hot-water fountains, or geysers, which occur in three principle localities: Norris, Lower and Upper Basins, and include 16, 23, and 45 geysers respectively. The first group is located on the Gibbon Canyon Road about 20 miles south of the Mammoth Hot Springs. The second, about 20 miles farther to the south near the Fountain Hotel, is 7,240 feet in altitude, and largest of the three basins, but its individual geysers are scattered over a considerable area and not as available for inspection. The Upper Basin offers the most interesting and largest fountains. The Giant Geyser, which plays every seven or twelve days for about an hour, is the largest of the park geysers since the Excelsior of the Lower Basin ceased to play in 1888. It shoots a stream of hot-water and steam to a height of between 200 and 250 feet. Another famous geyser of this basin is Old Faithful, situated in the southernmost part at an altitude of 7,300 feet. This geyser has the reputation of maintaining a regular schedule as it plays every 60 or 75 minutes for a period of about 4 minutes, shooting its water column aloft for 125 or more feet, and has kept to its schedule since its discovery in 1870. One geologist has estimated its flow at 3,000 barrels per eruption.

Although the park's volcanoes are extinct the steam fountains which still exist are dependent upon the heated rocks and gases far below the surface, which raise the temperature of the percolating surface waters under great pressure and cause them to return to the surface with tremendous energy, often bursting out in fountains of hot-water and steam. Other theories as to the origin of geysers have been advanced—that they are caused by chemical action or burning coal—but of late scientists have shown that geysers and hot-water springs are only found in regions where volcanic rock abounds, and the general conclusion points out that the steam source is the still hot lava deep within the earth.

The ascending steam and hot-water have caused great geological changes in the surface rocks through which they have passed, as may be seen at many points in the park, especially in the Grand Canyon of the Yellowstone, where the walls are colored for three miles below the Lower Falls by this action. Fully 1,000 feet of the wall, from the brink to the water below, is decomposed rhyolite varying in hue through orange, red, purple and yellow. Here, too, the ancient steam vents may be descried; while at the bottom of the canyon there are steam vents, hot springs and fumaroles which are still active.

Besides enabling the scientist to study the old vents and the discoloration of the walls, the Grand Canyon offers a fine example of erosion conducted on an immense scale within recent geological times, and its course was obviously determined by the easily eroded, decomposed rocks caused by the ascending steam and hot-water mentioned above. The two falls of the Yellowstone offer another feature of interest to the student, since they present a graphic example of the wearing effect of water upon the rocky walls and bed. The Lower Falls are the larger, being 308 feet in sheer drop.

The Mammoth Hot Springs are located 4 miles south of the northern park entrance at Gardiner, and here also is situated the hotel of that name together with the army post. Southwest of the hotel is Terrace Mountain, an outlying ridge of the rhyolite plateau, which is covered with thick beds of travertine, deposited by the hot-water in the form of terraces from which the mountain derives its name. The deposits of the hot springs at this place are far different from those upon the plateau. Here they are nearly pure travertine, with traces of silica—analyses indicate about 97 per cent calcium carbonate, while on the plateau the greater part of the deposits are of siliceous sinter, called "geyserite." This variation is on account of the fact that the Mammoth Springs are formed by steam coming up from far below through the water of the Mesozoic strata, the Cretaceous limestones furnishing the lime held in solution and deposited on the surface as travertine; while the mineral constituents of the plateau waters are derived mainly from highly acidic lavas carrying only a small portion of lime.

The terraces of the Mammoth Hot Springs present the appearance of banks of ice and snow with irregular basins of water in their glimmering stepped terraces. Among the important ones are Minerva, Cleopatra, Hymen, Pulpit, Jupiter, and Mound Terraces, while the springs which flow into and over them are named Jupiter, Diana, Palette, Naiad and others. The coloring of the spring waters here is marvelous in its harmony and brilliant tints, and is due to Algae, which grow in hot-water up to a temperature of about 185 deg. Fahr. Many of the springs present the appearance of boiling caldrons of water, although this is not the case, the bubbles being formed by escaping carbonic-acid gas.

Yellowstone Park, with its many geological formations, its ancient volcanoes, lava flows, hot springs, and geysers, presents a wonderful natural laboratory for the geologist, as well as the chemist. Its formation dates back to that of the central table land of the continent, and yet changes are still going on within its limits, though not as actively as heretofore, which make it an ever interesting problem for the scientist.

Cone of the Giant Geyser, as it appears when not playing.

The Giant Geyser, the largest geyser in the park.

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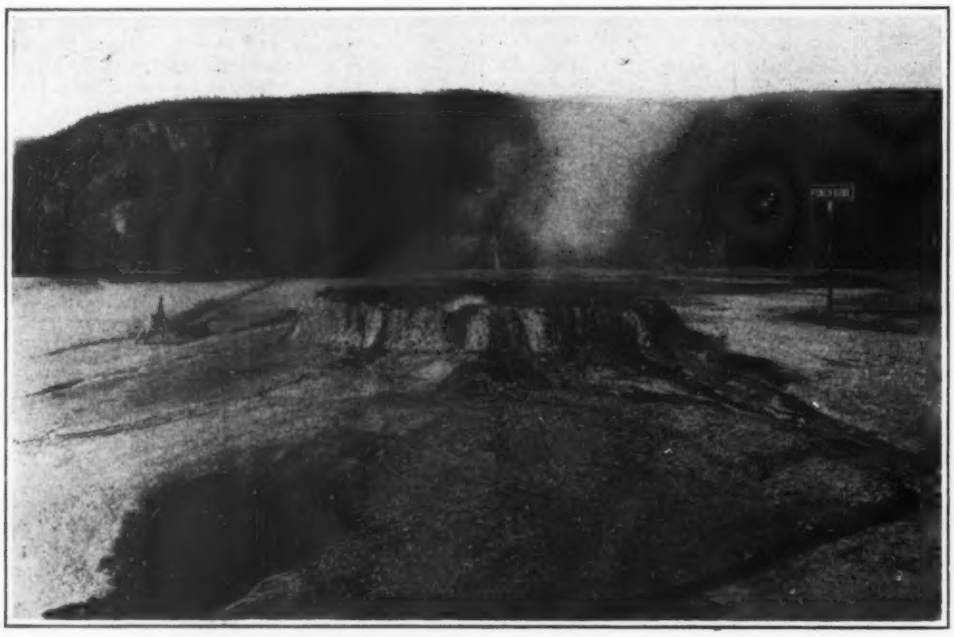
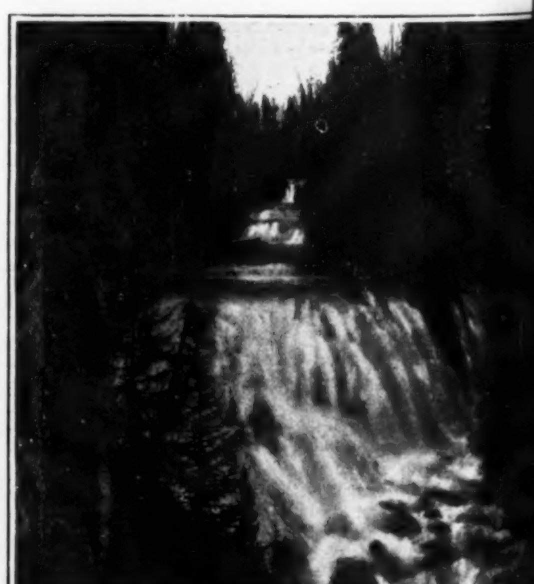


The Punch Bowl, located northwest of the Upper Geyser Basin.

Eagle Rest Rock, near Gardiner, the northern entrance

The

Washburn Hot Springs, on trail from the Grand Canyon to Tower Falls Station.



The Keppler Cascades, near Two Ocean Ponds.

The

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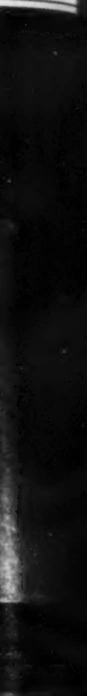
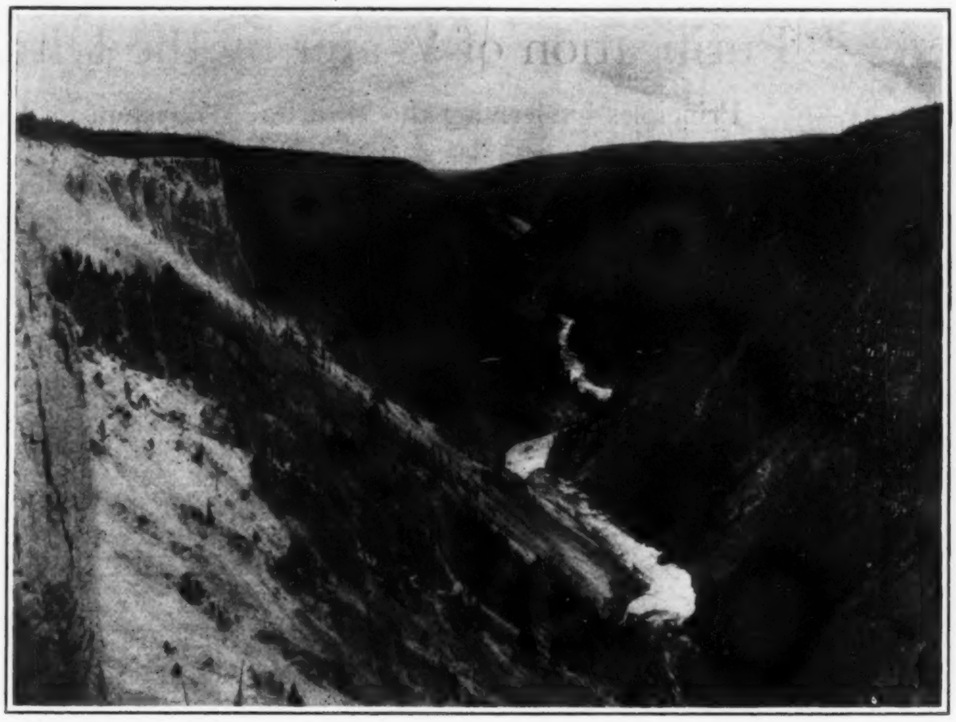


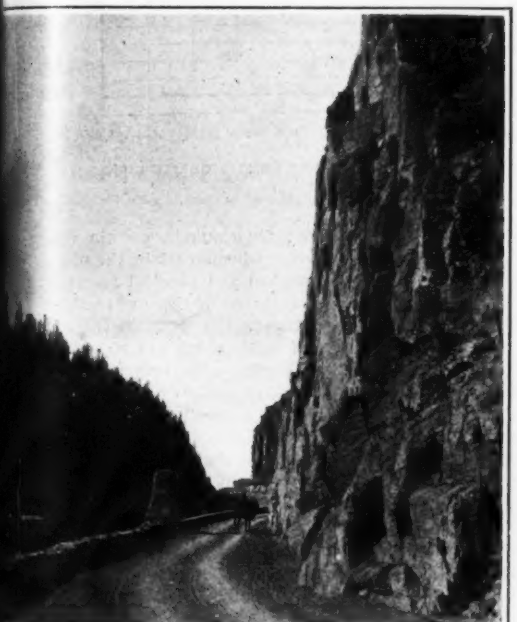
e park.

The famous "Old Faithful" Geyser.

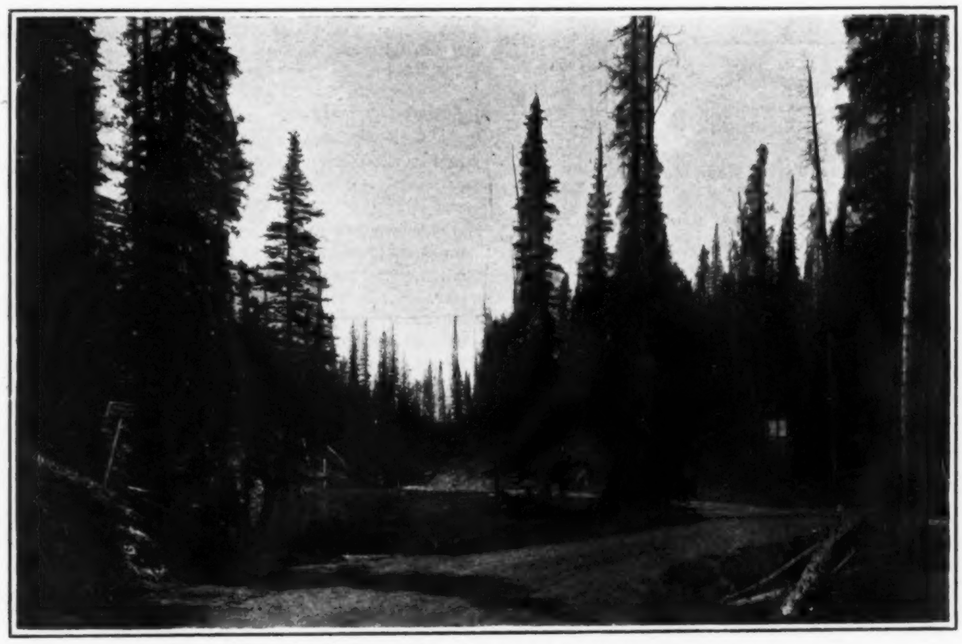


Looking up the Grand Canyon from Inspiration Point

n entrance

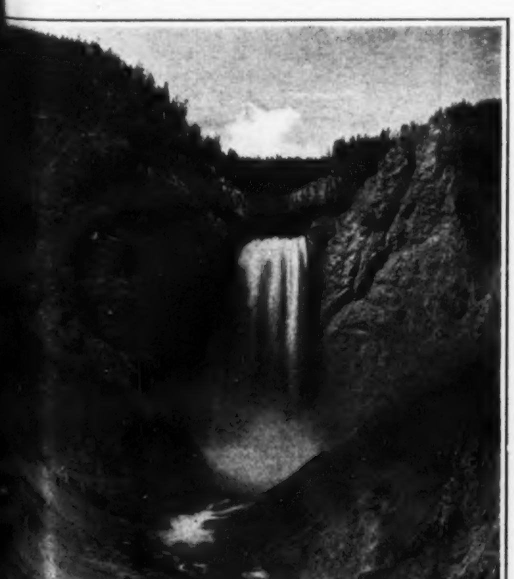


The Golden Gate, Swan Lake Basin.



The road along the Continental Divide.

Ponds.



The Great Falls of the Yellowstone.

A fishing hole on the Yellowstone River.

F THE ONE NATIONAL PARK

Purification of Water by the Ultra-Violet Rays*

Principles Underlying the Most Recent System for Destroying Germ Life

By M. von Recklinghausen, Ph.D.

It is a matter of common knowledge nowadays that the ultra-violet rays have a strong bactericidal power. Within the last few years this power of annihilating microbes by ultra-violet rays has been applied for freeing water of germs and a new industry has sprung up which produces water purifiers that make use of this new principle to sterilize water for drinking and other purposes. As this system is being applied successfully to large water plants, it is of interest for the professional water engineer to be fully informed on the principles underlying this most recent system of water purification.

The treatment of water by artificial light sources for the purpose of destroying its germ life dates back to

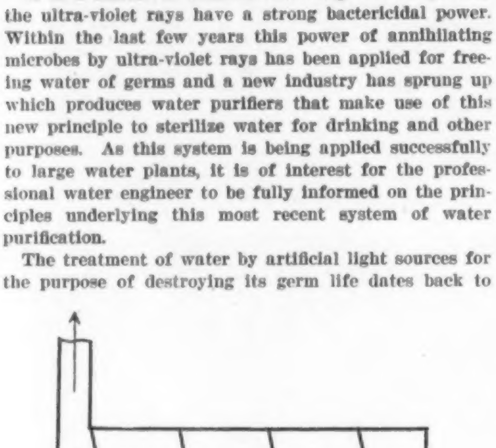


Fig. 1.—The De Mare sterilizer.

Downs and Blunt (1878). They found that the shorter the wave-lengths of the light the better the bactericidal action; and they were corroborated in this later on by Duclaux, Arloing, Roux, Geissler, and others. We owe to Duclaux the theory that sunlight is the most common and cheapest disinfectant known.

Marshall Ward (1892) completed these important studies by analyzing the effect of arc spectra thrown on infected agar plates; wherever they were struck by violet, and particularly by ultra-violet rays, they were disinfected and did not develop colonies. This English scientist sterilized Thames water by placing it in a tank equipped with a quartz window and submitting it to the rays of an arc lamp. This was proposed again later on by Lambert.

The first complete analysis of this bactericidal phenomenon of strong light sources we owe to Finsen, who in his famous light healing establishment laid the foundation of our modern knowledge of the action of light

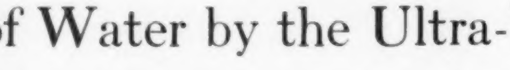


Fig. 2.—Spectrum of quartz lamp and of sunlight.

on germ life. As you will remember, the practical result of this work was the introduction of the light treatment of certain diseases by the Finsen lamp. We had, however, to await the arrival of really powerful sources of ultra-violet rays before applying light practically as a bactericidal agent for the purification of water.

This new source of ultra-violet rays was the mercury arc lamp built out of quartz. This mercury arc owes its origin to the work of Mr. Peter Cooper Hewitt, resulting in the well-known Cooper Hewitt illuminating lamps. When the ordinary glass of these lamps is replaced by quartz glass, that is to say, fused rock crystal, we obtain a container which allows the greatest amount of the ultra-violet rays produced by the mercury arc to be sent out from the lamp.

The first to propose the adoption of the mercury arc for the purification of water was De Mare. His sterilizer consisted of a lamp around which the water flows in a circular path (Fig. 1). Some years later, and nearly simultaneously, different ways of constructing water sterilizers with mercury lamps were tried out, and this work has resulted in the installation of several large and very many small ultra-violet ray water purifiers.

Before going into the details of this work I will mention the principle underlying the method of water purification by ultra-violet rays. We know from experiments that germs exposed directly to and at a very short distance (½ to 1 inch) from a powerful source of ultra-violet rays, such as we use in a modern sterilizer, are killed within a small fraction of a second, in some cases one-twentieth of a second being sufficient.

We therefore have to attend to two things: first, to an economic illumination of water with ultra-violet rays, and second, to make sure that every microbe contained in the water will be really led through the illuminated zone.

If we consider the latter point first, we come immediately to the conclusion that nothing must be in the water to intercept the rays, that is to say, there must not be any suspended matter in the water in the shadow of which the germ would be protected from the rays emitted by the lamp.

SOURCE OF ULTRA-VIOLET LIGHT.

Practically every source of light emits some invisible ultra-violet rays together with the visible rays. This can be studied by dissolving the light into its components by means of a quartz glass prism. Our human eye will see on such a spectrum only the well known colors of the rainbow. It will not see the wave-lengths below the red nor the wave-lengths beyond the violet; however, the latter can be easily demonstrated by certain properties they have; for example, certain dyestuffs show a fluorescent color when struck by the ultra-violet rays, also many chemical and physical reactions will take place under the influence of these ultra-violet rays and prove their presence in the spectrum thereby.

The artificial sources of light which are richest in ultra-violet rays are the electric arcs between metal electrodes, for instance, the iron arc, mercury arc, etc. All such arcing between metals is accompanied by disintegration of the metals themselves, therefore the electrodes have to be renewed from time to time. In the case of mercury, this renewing can be done in the simplest and easiest manner, namely, by condensing the mercury escaping from the arc and leading the so condensed mercury back to the electrode contained. Of course, the arc in this case has to be inclosed hermetically in a container, so as to avoid loss of mercury. The material we choose for making this container must be of such a quality that the desirable rays are not held up thereby, but, on the contrary, are allowed to escape freely. This material for the arc container is fused

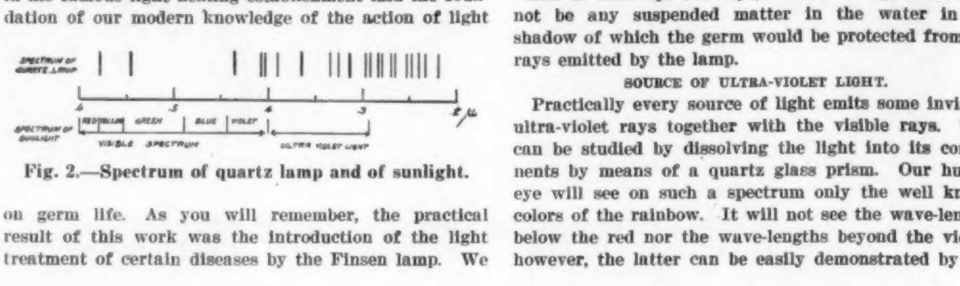


Fig. 3.—Seconds necessary to kill different types of germs at 200 millimeters from a quartz lamp burning at 66 volts, 3.5 amperes.

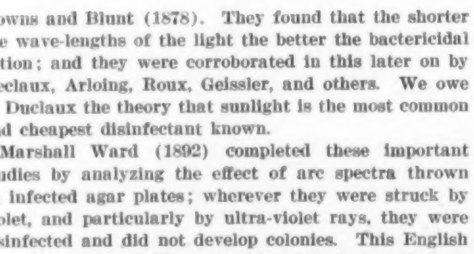


Fig. 4.—Comparative measure of ultra-violet activity of 220-volt quartz lamp burning at different voltages by three methods.

a, decomposition of citrate of silver; b, decomposition of potassium iodide; c, annihilation of bacterium coli.

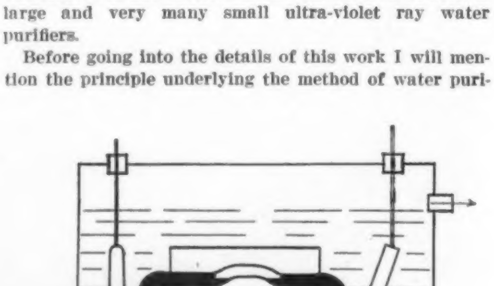
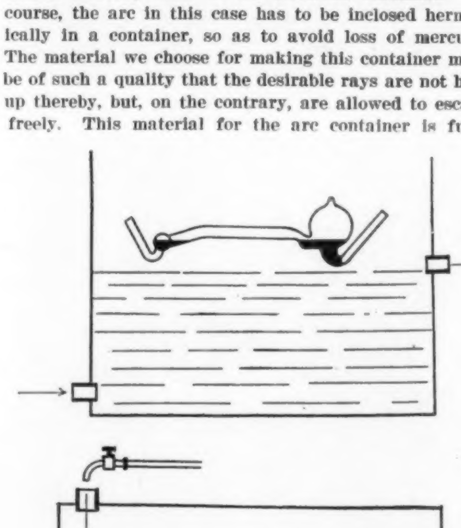


Fig. 5.—The Quartzlampen Gesellschaft.

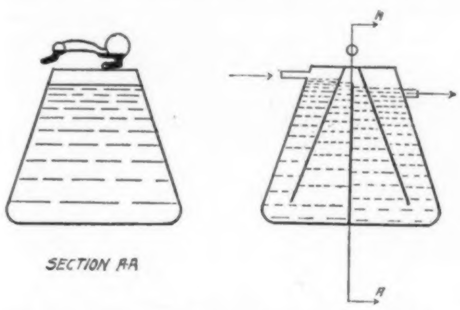


Figs. 6 and 7.—Upper figure: Apparatus used in experiments of Henri, Heilbronner, and Von Recklinghausen. Lower figure: Apparatus of Nogier.

* Paper read before the American Water Works Association Annual Convention at Philadelphia, and published in its *Journal*.

rock crystal, or more properly expressed, fused quartz.

For a given amount of electrical energy put into this arc, such a quartz arc lamp will attain a certain temperature depending upon its radiating capacity, that is to say, on its shape and surroundings. We have found that the amount of ultra-violet rays produced by such a quartz lamp is considerably more when running at a high temperature, than when it is run at a low temperature. The production of ultra-violet rays is, therefore, the more economical the higher the temperature of the lamp. This high temperature is obtained by raising the voltage of the lamp (Fig. 4). We are, however, limited to a certain temperature, namely, about 800 deg. Cent., by the fact that quartz if maintained for a long time at a higher temperature will devitrify, becoming thereby more or less opaque to the visible and invisible rays emitted from the arc. As in a water sterilizer we naturally want to approach the lamp as



Figs. 8 and 9.—Experimental apparatus used by the writer.

close as possible to the water, we must be careful to consider what has just been said about temperature and prevent the water from cooling the luminous part, rendering it thereby inefficient in its production of ultra-violet rays.

PHYSICAL CHARACTERISTICS OF ULTRA-VIOLET LIGHT.

The ether vibration can be distributed in four groups according to their wave-lengths, namely (1), the electric rays, (2) the infra-red rays, (3) the rays of the visible spectrum, (4) the ultra-violet rays.

Between the last electric rays and the first infra-red rays exists probably a group of still unknown qualities. All these rays travel at the same speed, namely, 300,000 kilometers per second. The wave-lengths are as follows:

1. Electric waves (Hertz, 1888) from several kilometers down to 3 millimeters.
2. Infra-red rays (Herschel, 1800) from 300 down to 0.76μ.[1]
3. Visible rays (Newton, 1666) from 0.76μ down to 0.40μ.
4. Ultra-violet rays (Ritter, 1802) from 0.40μ down to 0.10μ.

We are interested to-day in that last named group, number 4, namely, the ultra-violet rays whose upper limit is more or less vague (Fig. 2). It is sometimes placed at 0.3969μ; however, even shorter waves can be noticed by the eye, although not directly, but only by the fact that the crystalline in our eyes becomes fluorescent, giving thereby impression of gray on the retina. If people, therefore, have sometimes thought they were able to see ultra-violet rays, they really only saw their own crystalline. The lower limit of 0.10μ of the ultra-violet rays was obtained by Schumann and Lyman by working in vacuum with fluorspar prisms. However, these very short wave-lengths do not come into consideration in our case, because a few millimeters of air absorb completely the wave-lengths below 0.150μ and several centimeters of air absorb the wave-lengths below 0.1850μ. Several kilometers of air absorb the ultra-violet from 0.2943μ down. This wave-length is therefore the shortest of the sun's waves reaching our eye, and therefore the ultra-violet contained in the sun's rays are only the wave-lengths between 0.40μ and 0.2943μ.

[1] $\mu = \frac{1}{1000}$ millimeter = 10.000 Angström units.

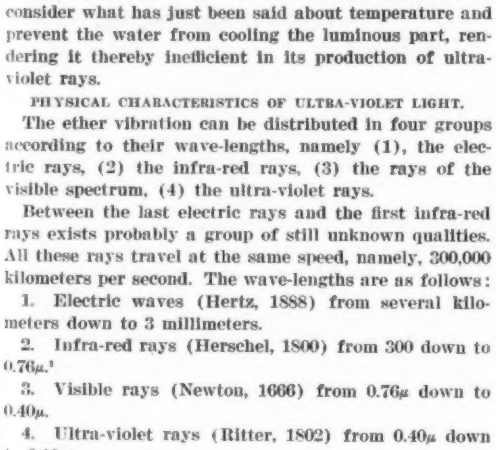


Fig. 10.—Large experimental apparatus designed to stir and circulate the water.

Quartz, the only material which we can apply for our lamps, absorbs practically everything below 0.20μ; therefore we may say that from the ultra-violet ray efficiency point of view it does not matter very much whether a quartz lamp is surrounded by a thin layer of air or by vacuum. Glass absorbs ultra-violet rays to an enormous extent, as may be seen from the fact that the bactericidal power of a quartz lamp is cut down to 1/1,000 if the lamp is surrounded by a glass tube.

BACTERICIDAL POWER OF ULTRA-VIOLET RAYS.

It was of interest to see whether different microbes had different resistivities against ultra-violet rays in the same way that they are different against disinfectants and heat, and we come to the astonishing result that they do not vary anything like as much. For instance, spores are often twenty times as resistant as the unprotected forms of germs against chemicals. We find that some are only 1.5 to 5 times as resistant against ultra-violet light as ordinarily unprotected water bacteria The table on page 10 (Fig. 3) shows a comparison of different types of germs in their resistivity. In each case under similar conditions cultures were made and the free germs put in clear water, care being taken, however, to avoid clumps of bacteria and also to avoid the presence of the nourishing medium, for otherwise the germs would have been protected more or less against the rays.

It has sometimes been thought that the bactericidal action of the ultra-violet rays was due to a small amount of hydrogen peroxide, which indeed forms itself by the exposure of water to the ultra-violet rays. However, this formation is so minute that it is barely noticeable after ten hours' exposure of the water, and we can surely say that the bactericidal effect is not due to the action of the so-formed disinfectant, but is a specific typical action of the ultra-violet rays on the germ. It is not likely that by the action of the rays, during such a short period, the entire bacteria should be chemically changed, coagulated, or otherwise modified, but it is more probable that some ferment, or similar product contained in the cell, is modified by the rays, and thereby poisons the system of the cell.

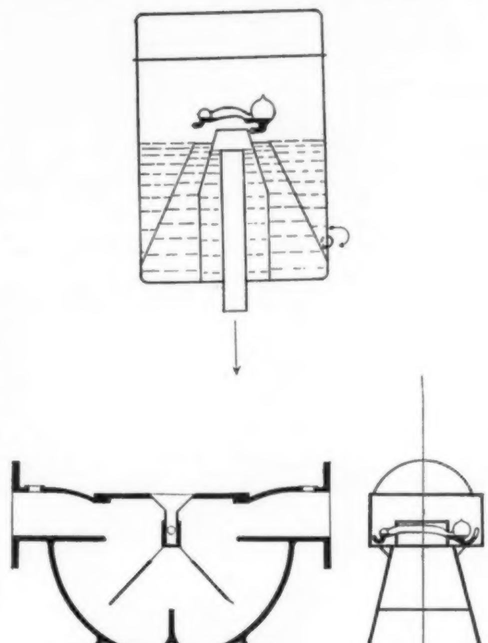
We have often been asked whether the germs struck by the light may not be simply stunned, and may survive again afterwards. In answer to this I will say that the methods of making the counts in Europe would enable one to find out whether there is any reviving. These counts extended over a period of usually fifteen days and never have shown any indication of revival.

QUANTITOMETRY OF ULTRA-VIOLET RAYS.

The luminous power of light sources is usually measured by comparing them with standard lamps. The moment that the light one wants to measure has a color different from the standard lamp, great difficulties arise, based on the fact that we do not really compare the two lamps physically, but only physiologically.

The difficulty of determining the *ultra-violet* candle-power of a lamp is far greater again, as we are not sensible to these rays at all. To get some idea of the strength of ultra-violet source we have therefore to create new means and units of comparison. Many different chemicals and physical reactions take place in the ultra-violet light. One may, therefore, base a measure of the ultra-violet candle-power on the speed and strength of such a reaction. The most typical and most convenient reaction of this kind is the blackening of photographic paper. We have found that a mercury quartz lamp will blacken paper about four times as quick as the same lamp screened behind a glass plate. An ordinary sensitometer can be built embodying this principle. Another reaction of the ultra-violet rays may be considered by comparing the amount of fluorescence produced by the lamps, but both of these methods of measuring will only allow us to compare light sources of similar composition. They do not give us what is really most interesting for us, namely, a measure of the *bactericidal power* of a lamp, and we therefore thought it best to adopt a real biologic test for the measure of the abiotic strength of quartz lamps. There remains, therefore, nothing for us to do but to establish a standard source of ultra-violet, that is to say, a laboratory standard composed of a certain lamp which is so kept that it is most unlikely to change in candle-power, and compare the action of this lamp with the action of the lamp one wants to measure on one and the same cultures of germs. The way we proceed is as follows: We make a culture of paramecies which are very similar in their sensitivity to ultra-violet rays as ordinary water bacteria. As a matter of fact, they will stand about six times the exposure that bacterium coli will stand, as Fig. 3 shows.

The sensitivity of such a culture is determined by exposing a drop of it at a defined distance from the laboratory standard quartz lamp. Another drop of it is



Figs. 11 and 12.—Typical apparatus that stirs water being treated between successive illuminations.

exposed at the same distance to the lamp one wants to measure, and the time necessary for killing gives the indication of the relative value of ultra-violet candle-power. We have chosen paramecias because they are easily observed under a microscope, having a rather violent motion while alive, and naturally no motion when dead. A few observations will, therefore, give us within a few minutes a definite idea of the bactericidal power one wants to measure.

I may say that we have checked figures so obtained with the effect on coli cultures, and can see thereby that we have a fairly safe process for determining by comparison the ultra-violet candle-power of a lamp.

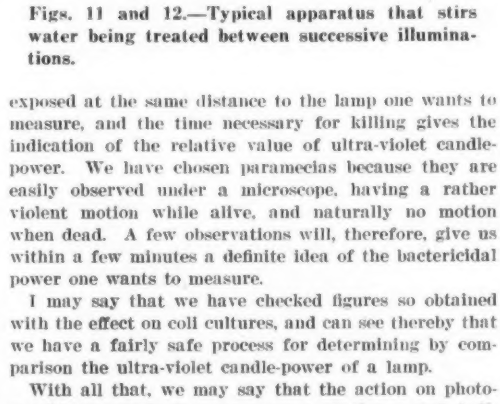
With all that, we may say that the action on photographic papers is, in most cases, a precise enough indication of the ultra-violet candle-power, as may be seen from Fig. 4.

It is natural that the electric characteristics of the lamps for these measures are checked up by the usual electrical instruments indicating the amperage and voltage of the lamp.

DEVELOPMENT OF THE STERILIZING APPARATUS.

The experiments we made at the Sorbonne laboratory, as well as the experiments of others working in this field, were started by exposing polluted water in containers to the light of the quartz lamps. These experiments allowed us to get data for the construction of sterilizing apparatus where the water was circulating continually through the illuminated zone.

As examples for the simplest form of apparatus, I will



Figs. 13 and 14.—Showing pistol lamp applied to flumes.

mention the sterilizing tank which we used in our preliminary experiments (Fig. 6), and Nogier (Fig. 7) and the Quartzlampen Gesellschaft (Fig. 5). In all of these experiments the water was simply passed in a straight flow underneath or around the source of the ultra-violet light. We found the results with this type of apparatus to be irregular, and came to the conclusion that this was due to the fact that the water, although clear, still contained some microscopic suspended matter which, when the water was flowing straight, would allow microbes to be shielded.

We therefore considered it advantageous to expose the water a second and third time to the light, after having stirred it between illuminations. In this way we expected to turn over such microscopic particles and have them therefore exposed on all sides to the action of the lamps. A typical case of such apparatus was used by us in experiments at the Sorbonne, and is shown in the design Figs. 8 and 9. The water in a similar apparatus of considerably larger size (Fig. 10) flowed through four illuminated zones, and stirred itself up through its flow around the bends of the canal between the luminous zones. The results were very satisfactory, as we obtained sterilization from about 5,000 germs per cubic centimeter down to less than 10 per cubic centimeter, the consumption of electric energy for the lamps being at the rate of 144 kilowatt hours per million gallons. The submitting of the water to successive illuminations, and stirring up during illumination, can also be done with a single lamp by so arranging baffles that the water is led several times toward and away from the source of the light (Figs. 8 and 9). Typical apparatus of this kind is shown in the B2 (Fig. 11) and C3 (Fig. 12) apparatus. The former apparatus, B2 type, uses only perhaps one fourth of the light emitted by the lamp. However, the apparatus is easy to handle and of a small size.

The C3 apparatus was constructed in a somewhat different way, with a view of using a greater proportion of ultra-violet. The lamp was protected from contact with the water by inserting it into a chamber fitted with quartz windows, which chamber was submerged in the tank containing the water. Three contacts of the water with the light are obtained in this apparatus.

It was desired to so construct the lamps that practically all their light could enter into the water and exert its sterilizing action. The so-called pistol lamps which have a U-shaped luminous tube (Fig. 15) allow this to be realized, the luminous part being inserted into quartz tubes, which protect them from contact with the water (Figs. 13 and 14). Such pistol lamp equipments can be inserted into flumes through which the water flows, and give the water several successive illuminations (Figs. 13, 14). The necessary stirring action in the water is obtained by baffle plates placed in the lamp axis whereby fairly violent stirring is taking place near the lamp.

The largest lamp unit made so far is the 500-volt 2.5 amperes, pistol lamp, and a maximum number of ten such lamps are inserted into a single flume.

As to the depth of the water in sterilizing apparatus, theoretically the best will be a very great depth of the water. We have observed strong bactericidal action even through three feet of water, the ratio being practically, as may be expected, inversely as the square of the distance, that is to say, for instance, one ninth of bactericidal action at three times the distance. Calculation and practice have shown us that it is good to provide, if possible, two feet depth of water in larger apparatus. Of course in apparatus working with water which is highly colored this depth may be reduced, as otherwise it would make the apparatus unnecessarily cumbersome.

The whole system having been developed abroad, it is only natural that there are considerably more such installations in Europe than in this country. Small installations are used for producing water for drinking and surgical purposes in hospitals, schools, etc., also for bottling purposes. The first large installation of a C3 apparatus (rate of 150,000 gallons per day) has been running since November, 1910, in a suburb of Rouen. The hygienic results from this plant are very satisfactory, typhoid in the district fed with the water from this plant being extinct, while it exists still in the surrounding districts which use similar water without ultra-violet ray purification.

A plant with four 220-volt pistol lamps has been running for over a year in Saint Malo sterilizing the water at a rate of 750,000 gallons per twenty-four hours.

Many C3 apparatus are running in France, in some cases two being run in series, with always very gratifying results. The largest sterilizing unit composed of a flume with ten 500-volt pistol lamps is sterilizing the water for the city of Luneville, France (Fig. 16). This supply consists of 1,500,000 gallons of river water and 375,000 gallons of spring water. The water in this case, which in its raw state is extremely muddy and rich in colloidal matter, is filtered through a rough and slow sand filter without the addition of coagulants, at a rate of about 7,000,000 gallons per acre. In case of a biological filtration this type of water would have to be filtered at the rate of 2,500,000 gallons per acre.

On account of some turbidity, and also an often deep color of the filtered water (up to 40 U. S. standard) this plant has an exceedingly high current consumption, namely, 130 kilowatt hours per million gallons; during most of the time two thirds of this consumption would be ample.

The first application of the ultra-violet ray system for sterilizing water on a large scale in this country was

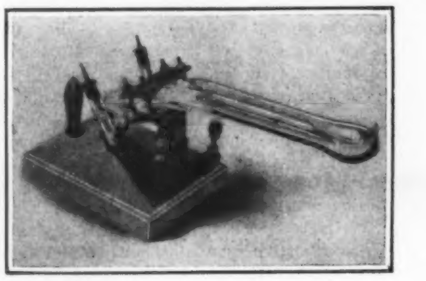


Fig. 15.—The pistol lamp.

started recently in New York, where the water of a swimming pool is continually being circulated through a rapid filter and a sterilizing flume, equipped with two 220-volt pistol lamps, the flow being about 5,000 gallons an hour.

As mentioned in the theoretical part, the ultra-violet rays must be able to strike the microbe; where any suspended matter is interposed, the bactericidal action cannot take place, because the microbe is in the shadow. It is certain therefore that only clear water can be submitted to the ultra-violet ray treatment for its sterilization. That is to say, in most cases it is necessary to filter the water before the same is submitted to the action of the lamps. As color in solution will absorb ultra-violet rays to a certain extent, it is evidently better to also free the water from coloring material before submitting it to the rays.

The question of suspended matter in the water is of somewhat greater importance. Sometimes water with little suspended matter may be more difficult to sterilize than water with far more suspended matter. The reason for this is that it will depend not only on the size and quantity of the suspended matter, but also on its biological quality. That is to say, suspensions of purely mineral nature, which do not inclose any microbes, and to which few microbes are attached, handicap the sterilization of the water very much less than suspended particles in similar water which are heavily covered with microbes, and particularly so if microbes are inclosed in these particles, because it is then most likely

Fig. 16.—Sterilizing apparatus at Luneville, France, in which ten pistol 500-volt lamps operate on one 1,500,000 gallons of water a day.

that a repeated exposure to the rays will be necessary to penetrate to the inclosed germ life.

If the suspended matter is of smaller size than the germs, like colloidal clay, we expect such turbidity to act more or less like color in solution, demanding simply more illumination than clear water. Experiments made with one of the B2 apparatus on water showing up to 20 turbidity seem to prove that such fine turbidity does not handicap sterilization very much.

From the economical point of view, the condition in which the water is submitted to the rays is evidently of great importance for the ultra-violet rays sterilization system. Physically ideal water, that is to say, water without suspended matter, turbidity of color, will need very little power in ultra-violet rays to become sterile. In large plants 50 kilowatt hours per million gallons will produce a great *over-dose* in ultra-violet.

Smaller installations are being equipped usually with charcoal or paper filters. In large plants naturally the filter question is an engineering proposition; so is the question of choice between mechanical and sand filters.

It seems that if the latter are chosen they can be speeded up to a great extent as against the speed for biological filtration and still give a physically pure enough water for ultra-violet ray treatment as, for example, the Luneville plant where the water is filtered practically at three times the rate of biological filtration for that particular kind of water. In other plants the filtration has been speeded up to 10,000,000 gallons to 12,000,000 gallons per acre, and we even tried with fair success 25,000,000 gallons per acre, followed by ultra-violet ray treatment. This will, naturally, always depend on the filtrability of the water.

Operating costs will vary with the size and the running hours of the plant, and the *coefficient of safety* one wants to give to the ultra-violet ray treatment. According to the quality of the water, I expect in large plants the current consumption will vary between 50 and 125 kilowatt hours per million gallons, allowing for a large safety coefficient. The labor charges are negligible, as the apparatus only needs an occasional cleaning and starting of lamps. Apart from this, the lamps have to be repumped and repaired from time to time.

In any engineering proposition we always try to adopt as large a *safety coefficient* as possible. If we rely on chemicals to disinfect our water, we must work right close to and sometimes even over the limit of the amount which will not make itself objectionable by producing taste and odor in the water.

In the ultra-violet rays we have a system where we may choose *our safety coefficient as high as ever we liked*, that is to say, we may *over-dose* our sterilization as much as we want without creating any objectionable features in the water, like taste and odor.

The Photokaleidograph*

An Apparatus for the Production of Kaleidoscopic Pictures.

THE kaleidoscope has not been used exclusively as a plaything for children. It has furnished many patterns for woven fabrics, embroideries, carpets and oilcloths. The combination of the kaleidoscope with the photographic camera has often been attempted, but with little success.

In the last few years my attention has been drawn to these matters in the course of my professional work for the Carl Zeiss Optical Company. We received a commission to construct a kaleidoscope of precision. After overcoming certain difficulties I succeeded in producing the instrument herewith illustrated, which can be used either for direct observation or for photographic reproduction of the kaleidoscopic patterns.

In this instrument a solid glass prism takes the place of the two inclined mirrors of the old Brewster kaleidoscope. The faces of the prism are cut accurately to the prescribed angle, polished and silvered. The prism is protected from injury by covering it with strips of black glass, cemented to its faces. The ends of the prism are cut perpendicular to the axis and polished, and the prism is inclosed in a brass tube, from which its ends only protrude.

The tube is mounted vertically above the horizontal photographic plate, measuring 13 by 18 centimeters (about 5 by 7 inches). The photographic lens is secured to the lower end of the tube. The distance of the tube from the photographic plate is adjusted to produce a sharp image, and this distance is fixed by means of a stop-ring, surrounding the tube. Several tubes of exactly the same diameter, containing prisms of different sizes and angles, are provided, and can easily be interchanged.

The object, which is to produce the photographed kaleidoscopic pattern by internal reflection from the faces of the prism, is itself a photograph on glass, which is pressed lightly, with the film side down, on the upper end of the prism, to which a drop of oil has been applied. The picture is usually larger than the sectional area of the prism, but only the part included in that area is reproduced and repeated on the photographic plate beneath. The illumination is furnished by a mercury vapor lamp, provided with a ray filter which transmits only the light of one of the violet mercury lines.

For the observation and selection of the patterns an inclined plane mirror is placed between the lens and the plate holder. This mirror reflects the kaleidoscopic image to a ground glass screen which can be observed by several persons at once. If it is decided to photograph the pattern, the mirror, which is mounted on a horizontal axis, is turned into a position in which it excludes light entering through the ground glass and allows the rays from the lens to fall on the photographic plate. The mirror is fastened in this position

* Translated from Dr. Pulfrich's article in *Die Umschau*.

during the exposure of about one minute. It is then turned back to its former position, in which it excludes all light from the plate and again reflects the image to the ground glass. (The entrance of light through the ground glass can also be prevented by closing a sliding shutter of sheet metal beneath the glass.)

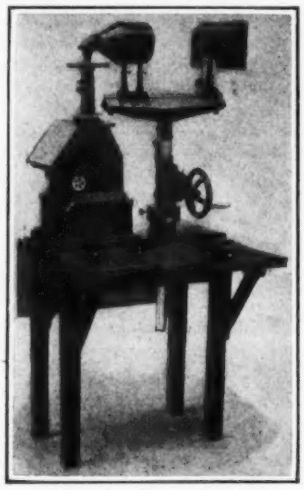


Fig. 1.—The Photokaleidograph.

Details of the picture may be traced on the ground glass screen. This device is often useful for the purpose of combining several kaleidoscopic pictures. A great variety of photographic transparencies may be used as objects, but photographs of other kaleidoscopic patterns are especially suitable.

Each of the prisms can also be used for the direct observation of kaleidoscopic combinations. For this purpose a special observing lens is substituted for the camera lens. The other end of the tube is fitted into a base so that the prism can stand erect on a table, over a drawing, which is illuminated by light entering the prism laterally from above.

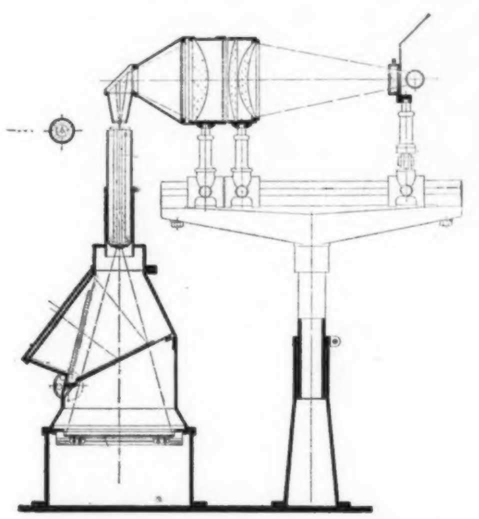


Fig. 2.—Diagram of the photokaleidograph.

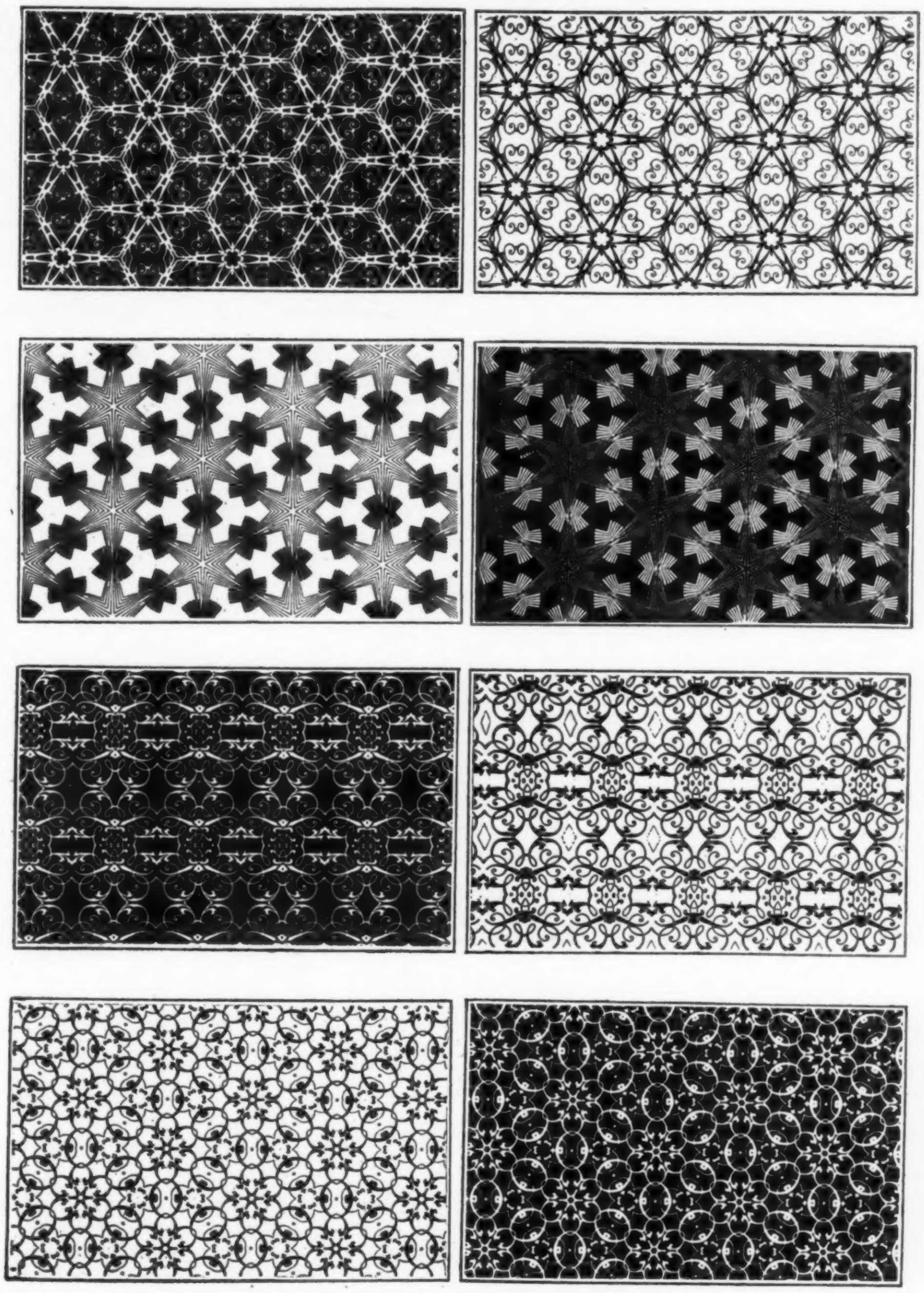


Fig. 3.—Photographs of kaleidoscopic patterns.

The Stars Around the North Pole*

The Determination of Their Proper and Irregular Motions

A KNOWLEDGE of distances of the stars is of fundamental importance in any attempt to describe the stellar universe. It is required, before answers can be given to questions on the average distances of stars from one another, their brightness compared with the sun, and the extent to which they reach in space. There are not more than 100 or 150 stars of which the distances have been measured with any degree of accuracy. Although this number is being steadily increased, it is only the stars which are comparatively near to the sun which can be treated individually. For the greater number we have to be content with average values which apply to groups of stars.

A map or a photograph of the stars gives only their bearings; that is to say, their directions as seen from the earth. It gives no information whatever about the distances. One star may be a hundred times as far away as its neighbor on the map. But if two maps are made, separated by a sufficient interval of time, some differences will be found in the relative positions of the stars. These indicate movements either of the stars themselves or of the point from which they are viewed. But the movements which are observed are merely changes of angular position. We cannot tell directly from them either the actual velocities or distances of the stars, but only the ratio between these quantities. It is, however, from the geometrical study of these small angular motions, supplemented by the information obtained from the spectroscope as to the velocities of stars in the line of sight, that our knowledge of their distances is derived.

The problem is in many ways analogous to one which has been completely solved. In the early days of astronomy the movements of the wandering stars or planets were noted. The essential characteristics of the movements were embodied in geometrical formulæ by the Greeks. In the course of time Copernicus showed that these formulæ could be most simply interpreted on the assumption that the earth revolved around the sun. His purely geometrical arguments were, it is true, powerfully reinforced by the revelations of Galileo's telescope. Nevertheless, the planetary system as formulated by Copernicus and Kepler resulted from the observation of the angular movements of the planets and the attempt to give them the simplest possible geometrical interpretation.

Further study of the planetary system has been guided and controlled by the law of gravitation. But the observational data on which our very complete knowledge of the solar system is based, the distances, sizes, and movements of all its members, are a long series of measures of the angular movements as seen from the earth. Linear measurements are only required to obtain the form and dimensions of the earth itself, and thus supply a base line to determine the scale of the system.

The fixed stars present us with a very similar problem. From the study of their small angular movements, supplemented by spectroscopic observations, it is required to construct as far as possible a model of the stellar universe. Such a model would give for each star:

(1) Its actual position in space measured along three axes with the sun as origin.

(2) The velocity in kilometers a second in each of these directions.

(3) The brightness or luminosity, taking the sun as unit.

(4) The mass.

(5) The size.

(6) The physical and chemical constitution.

Of these elements the mass is at present only determinable for double stars, and the size for eclipsing

* An address delivered at the Royal Institution by Dr. F. W. Dyson, F.R.S.

variables. The physical and chemical constitution are known from spectroscopic observations for a considerable number of stars. But the distance and absolute brightness can be found only for a limited number of the nearest stars. Average results can, however, be

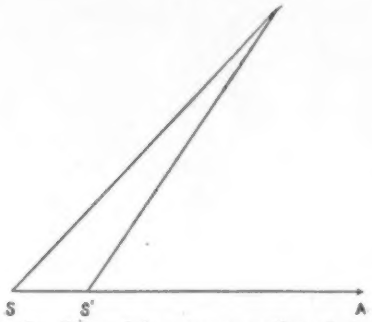


Fig. 1.—Determining proper motion of stars.

obtained for the more distant stars, which tell us:

(1) The number within certain limits of distance from the sun.

(2) The mean velocities of these stars, and what percentage are moving with given velocities, say, for example, between 10 and 20 kilometers a second.

(3) Whether these velocities are irregular or show anything in the nature of streaming in particular directions.

(4) What proportion of the stars are comparable with the sun in intrinsic brightness, and what proportion are ten times or one tenth as bright, and so on.

Such a description of the stellar system is, to a large extent, within the powers of astronomers, and we nurse the perhaps extravagant hope that generalizations will be discovered which will lead to the formulation of dynamical laws on the constitution of the stellar universe.

A small area round the pole has been chosen as a sample, because this part of the sky has been observed more fully than any other of equal extent. It forms a small cap extending to a distance of 9 degrees from the pole, and covering about 1/160 of the whole sky. In the year 1855-1856 Carrington, an English amateur astronomer, well known from his observations of sunspots, using a very small transit instrument, observed the positions of all the stars in this part of the sky from the brightest down to very faint stars between the tenth and eleventh magnitudes. He thus constructed a catalogue, giving with great accuracy the positions of 3,700 stars for the year 1855. About the year 1900 these stars were re-observed at Greenwich by a combination of visual and photographic observations. By comparison with the positions as given in Carrington's Catalogue, the angular movement of each of these 3,700 stars in forty-five years is determined. These angular movements, or "proper motions" as they are technically called, are the data available for obtaining the actual positions and movements of the stars in space. We have to solve the geometrical problem of making these stars stand out in three dimensions, so that we may see them as we see a picture in a stereoscope.

Now the proper motions of stars are very small. The star of largest proper motion moves only 870 seconds a century. An idea of the smallness of this motion may be obtained from the fact that it will take two centuries to move a distance equal to the apparent diameter of the sun or moon. There is no star among those near the north pole with a proper motion so great as this. The following table gives an abstract of the proper motions of the 3,726 stars under consideration:

TABLE I.

Limits of Proper Motion.	Number of Stars.
>40″ a century	2
20″—40″ " "	39
10″—20″ " "	134
5″—10″ " "	574
3″— 5″ " "	977
0″— 3″ " "	2,000

It is clear that the stars with large proper motions must either be moving fast or must be comparatively near. These are the alternatives, but for an individual star it is impossible to decide between them.

The table shows how largely the propor motions of stars vary in direction. They differ just as widely in direction. Some signs of irregularity in the directions were first detected by Sir William Herschel, who found that the movement of seven quick-moving stars situated in different parts of the sky were approximately directed to one point. He observed that this would result if the proper motions arose not from the movement of the stars themselves but from that of the point of observation in an opposite direction, and concluded that the solar system was moving toward a point in the constellation Hercules. This conclusion was not universally admitted for some time, but researches by Argelander, Airy, Bessel, and others demonstrated a regular drift among the stars, such as would arise if on their otherwise irregular movements were superposed this common motion. A large number of researches have been made on the exact direction of the sun's motion, and it is now established with some certainty that it is toward a point in right ascension 18 hours and declination 35 degrees north, not far in direction from the bright star Vega. The speed of the sun's motion through space has been determined by spectroscopic observations. On the average, stars near Vega appear to be approaching us, stars in the opposite direction to be receding from us. In this way Prof. Campbell has found from the observed velocities of 1,500 stars that the solar system is moving at the rate of 19.6 kilometers a second.

The fact that the sun is moving with a velocity of 19.5 kilometers a second in a known direction supplies us with a means of determining the average distances of groups of stars. This velocity carries the sun forward in a century a distance equal to 412 times the sun's distance from the earth. If at the beginning of the century the sun is at S (Fig. 1), and at the end has moved to S', the angular distance of a star situated at P, and having no motion of its own, will have increased from ASP to $AS'P$. The difference of these angles, which is the proper motion of the star, is SPS', and it follows that the distance (SP) can readily be deduced. We cannot, however, say that any individual star is at rest, but if we take a sufficiently large group of stars it is legitimate to suppose that in the average the peculiar movements of the separate stars are eliminated, and the mean distance of the group can be inferred.

Fig. 3.—The distribution of the angular and linear velocities of the stars.

During the last twenty or thirty years the proper motions of many stars have been determined by the comparison of modern with earlier observations. Particularly the reduction by Dr. Auwers of Bradley's observations made in 1755 led to the accurate determination of the angular movements of the brighter stars. The proper motions of fainter stars have been found by comparison with observations made in the first half of the nineteenth century. These have all been utilized to determine the direction and angular amount of the drift produced in the stars by the motion of the solar system through space. The results were very puzzling, because different mathematical methods and different groups of stars gave widely different directions for the solar motion. The cause was discovered about ten years ago by Prof. Kapteyn, who found in the proper motions of the stars another indication of regularity, or perhaps it might be called a systematic irregularity smaller than the one discovered by Herschel, but unmistakable when once pointed out. He interpreted these systematic irregularities to mean that the stars are divisible into two groups streaming through one another in opposite directions in space. Prof. Kapteyn's discovery has been submitted to mathematical analysis by Prof. Eddington and Prof. Schwarzschild. Their researches have illuminated the whole subject of stellar motions; and though they are not in entire agreement, they leave no doubt of the existence of a preferential movement among the stars toward the north part of Orion and the diametrically opposite direction in the constellation of the Serpent.

We must next consider the *motus peculiares*—the irregular movements of the stars themselves. From observations of the velocities of stars in the line of sight, especially from those made at the Lick Observatory under Prof. Campbell's direction, it is known that a few stars are moving with great velocities, such as 100 kilometers a second, while others are moving very slowly. The following analysis of Campbell's results for one class of stars—those of spectral type A—(taken from a paper by Prof. Eddington) shows the proportion of slow-moving, moderate, and quick-moving stars:

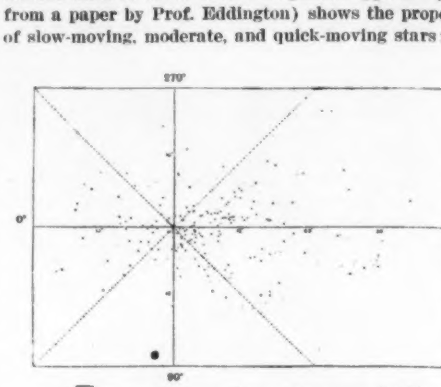


Fig. 2.—Proper motions of Group A5-F9.

TABLE II.

Velocities	Number of Stars observed.	Number of Stars given by error law
0— 5 kil/sec	55	53.4
5—10	47	46.2
10—16	30	38.3
16—25	30	27.4
25—40	10	6.7
>40	0	0

Comparison with the third column of the table shows that the velocities are distributed in accordance with the law of errors. The law is identical with that found by Maxwell for the velocities of the molecules of a gas. In the case of a gas, this distribution of velocities results from the frequent collisions. For the stars there is no evidence that it has resulted from their interaction. It must be regarded as an observational fact which permits us to say that the distribution of the velocities of the stars is stated concisely by this simple mathematical formula.

The three movements—the movement of the solar system in space, the streaming of the stars, and their irregular movements are all shown in their proper motions. The figure (taken from a paper by Mr. Jones

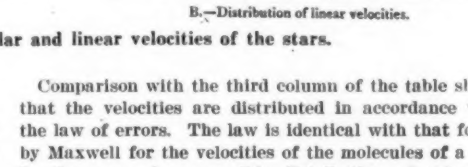


Fig. 4.—Distribution in distance of the star in Carrington's catalogue.

—Monthly Notices of the R. A. S., vol. lxxiv., p. 196) exhibits the proper motions of some of the brighter stars situated near the north pole. If the stars had all been placed at the origin they would in a century have spread out as shown in the figure.

This spreading out has been caused by:

(1) The solar motion, which has shifted the center of gravity of the swarm toward 180 degrees.

(2) The peculiar motions of the stars themselves, which have spread out in the directions toward 90 degrees and 270 degrees.

(3) The streaming in the direction of 0 degree to 180 degrees, which, combined with the peculiar motions, has made the spreading out much greater in this than in the perpendicular direction. In this part of the sky the

streaming happens to be in the direction of and opposite to the solar motion.

Let us now consider the proper motions of the 3,700 stars observed by Carrington in the light of these discoveries. The shift of the center of gravity caused by the solar motion is 1.44 seconds a century. As we know how far the sun has moved in a century, this gives the average distance of these stars as fifty million times the distance of the sun from the earth. Turning now to the proper motions in a direction perpendicular to that of the sun's motion, which arise from the *motus peculiares* of the stars themselves. Counting these cross proper motions, we find them divided as shown in Table III.

TABLE III.

16 are greater than 15.0" a century					
25	lie between	10.0"	and	15.0"	a century
33	" "	8.0	"	10.0	"
66	" "	6.0	"	8.0	"
191	" "	4.0	"	6.0	"
873	" "	2.0	"	4.0	"
2504	" "	0.0	"	2.0	"

When suitable allowance is made for the accidental error in these observations, it is found that the number less than any given amount τ can be represented by the following algebraical formula:

$$3{,}700 \frac{\tau}{\sqrt{(\tau^2 + 1.47^2)}}$$

The distribution of the angular velocities is shown in Fig. 3 (A), the total number being represented by the area of the curve; the number, for example, between 2 seconds and 3 seconds a century is given by the shaded portion.

Now suppose that all these stars were actually moving with the same velocity, say 10 kilometers a second, then their distance could be calculated, those with proper motion 1 second a century being forty million times as distant as the sun, those with proper motion 2 seconds a century twenty million times, those of 4 seconds a century ten million times, and so on, the larger the proper motion the nearer the star to us.

This is only an illustration; the velocities of the stars are not all the same, but are distributed according to the law of errors. If the distance of each star were known, then by dividing the velocity by the distance the proper motion would be found. We have to find how many are at one distance, how many at another, so that the proper motions will be distributed in accordance with the law found from the observations.

Fig. 3 (B) shows the distribution of linear velocities, the shaded portion, for example, giving the proportion moving between 30 and 40 kilometers a second. Now the distribution of angular velocities is shown in (A), and the question arises: How must the stars be distributed in distance for these two laws to harmonize?

This is a mathematical problem which can be solved fairly easily, and the answer is that the stars must be distributed in distance according to a law shown graphically by the curve in Fig. 4. (The distribution of velocities $\frac{h}{\sqrt{\pi}} e^{h^2v^2} dv$ combined with the distribution of proper motions $\frac{d\tau}{a}\left(1 + \frac{\tau^2}{a^2}\right)^{-\frac{3}{2}}$ leads to the partial distribution $2a^2h^2re^{-a^2h^2r^2}dr$).

In the diagram, distances are measured horizontally, the unit of distance being that at which a star's parallax is equal to 1 second (or 206,265 times the distance of the earth from the sun). It is convenient to have a name for this unit, and in what follows the word *Parsec*, suggested by Prof. Turner, will be adopted. With this unit a distance of 100 in the diagram denotes twenty million times the distance of the sun from the earth. The following table gives the percentage of stars between certain limits of distance:

TABLE IV.

6 per cent of the stars are between	0	and	100	parsecs
5 " " " "	100	"	200	"
10 " " " "	200	"	400	"
43 " " " "	400	"	700	"
36 " " " "			>700	"

It follows that 88 per cent of the stars in Carrington's Catalogue; that is, 88 per cent of all the stars brighter than about 10.5 magnitude, lie between 20 and 150 million times the distance of the sun from the earth. This law of the distribution of the stars is at first sight rather surprising. It should be remembered that the only stars at a great distance which are included are those which are intrinsically very bright, and these form only a small proportion of all the stars. Prof. Eddington has found that a similar law holds for stars brighter than 6.0 magnitude.

Having found the law of distribution of the distances of these stars, it is not difficult to determine something about their absolute luminosities, i. e., how they would compare with the sun in brightness if placed at an equal distance from us.

If the sun were at a distance of one *parsec*, it would appear as a bright star, brighter than the first magnitude—actually of magnitude 0.5; if at a distance of 100 parsecs, its magnitude would be 10.5. Now all the stars in Carrington's Catalogue may be taken as brighter than 10.5 magnitude, thus at least 95 per cent of these stars are intrinsically brighter than the sun, and at least 80 per cent are four times as bright, 40 per cent are sixteen times as bright, and 8 per cent are fifty times as bright.

We may conclude that the great majority of the stars brighter than 10.5 magnitude are intrinsically brighter than the sun, and a considerable proportion very much brighter.

The distribution of bright and faint stars in a given volume of space is quite different, and contains a much larger proportion of faint stars. If we make the assumptions that the density of the stars and the proportions of bright and faint ones is the same at the different distances from the sun within which these Carrington stars are situated, it is possible to find the actual number of stars of different luminosities in a given volume of space. In a sphere with radius 100 parsecs, or twenty million times the distance of the earth from the sun, there are, at least,

24 which are	100 times as luminous as the sun	
340 "	50 " " " "	
1,530 "	25 " " " "	
4,840 "	10 " " " "	
23,200 "	1 " " " "	
93,300 "	1/10th the luminosity of the sun.	

The data only admit of a rough determination of the number of very faint stars and the number of very bright ones. The figures give a general indication of the density of the stars in space and of their intrinsic brightness, and serve to direct attention to the fact that there are many stars much less luminous than the sun, and a certain proportion very much more luminous.

The conclusions drawn up to this point have been based entirely on a consideration of the proper motions of the stars, irrespective of whether they are bright or faint, provided only that they are sufficiently bright to have been observed by Carrington. But as the apparent magnitude of a star depends on its distance as well as on its intrinsic brightness, we naturally expect some assistance in assigning the distances of these stars from their magnitudes. The brightest star in this small area round the north pole is Polaris, the magnitude of which is 2. (It may be remarked incidentally that the distance of the pole star has been actually measured. It is twenty parsecs, or four million times the distance of the sun from the earth, and if it were at the same distance as the sun it would appear to be 100 times as bright.) Then there are about twenty stars which are visible to the naked eye. The following table gives the actual number of stars of different magnitudes (photographic):

TABLE V.

Brighter than 7.0m.	61 stars
From 7.0m. to 8.0m.	124 "
" 8.0m. " 9.0m.	397 "
" 9.0m. " 10.0m.	998 "
Fainter than 10.0m.	2,140 "

Then, again, the stars may be divided into groups according to the physical characteristics revealed by the spectroscope. The researches of Kapteyn, Campbell, and others have shown—at any rate, for the brighter stars—remarkable relationships between the distances and velocities of the stars and the type of spectrum which they manifest. It is therefore desirable to examine the proper motions of stars of different spectral types separately. The spectra of many thousands of stars have been determined at Harvard College, under Prof. Pickering's direction, by Miss Cannon. The different classes are indicated in the Harvard classification by the letters B, A, F, G, K, M, with further subdivisions. The B stars are characterized by the presence of helium, the A stars by series of broad hydrogen lines. In the F stars the hydrogen lines are thinner, and fine metallic lines are shown. The G stars are very like the sun, full of metallic lines, and with broad lines due to calcium. In the K stars the two calcium lines are still broader, and there are many fine metallic lines. The M stars are characterized by broad absorption bands. This arrangement places the stars in the order of their temperatures; the B stars are the bluest and hottest, and the M stars the reddest and coolest. The character of the spectra of about 800 of the stars in Carrington's Catalogue is given by the Harvard observations.

For the fainter stars the spectra have not been determined, but they can be inferred in another way. As the blue stars are more active photographically than the red stars, if a red and blue star have the same visual magnitude, the magnitudes estimated from the images on a photograph will differ considerably, and this difference is an index of the color and thus of the type of spectrum. Now the visual magnitudes of most of these faint stars have been very accurately determined at Potsdam by Messrs. Müller and Kron (and have been kindly communicated in manuscript), and the photographic magnitudes have been determined at Greenwich. The differences have been taken between the photographic and visual magnitudes, and serve to classify the stars according to their temperature.

Separating the stars into two groups, those which are brighter than 9.5 magnitude on the Potsdam scale of magnitude, and dividing each group into four classes according to the color index, the parallactic motion, i. e., the mean angular movement per century arising from the motion of the sun through space, is determined for each class. The results are exhibited in the following table:

TABLE VI.

Spectral class	Color index	Stars brighter than 9.5m.		Stars fainter than 9.5m.	
		Number	Parallactic motion	Number	Parallactic motion
			"		"
K—M	>8	175	0.65	269	0.36
G—K	4 to 8	168	1.31	428	0.95
F—G	−1 to 4	264	2.58	959	1.53
A—F	<−1	240	1.97	460	1.28

In this table the red stars are on the top line; the third line consists of stars which are in the same stage of development as the sun; those in the second line are somewhat cooler and redder; those in the last line hotter and bluer. The last line includes a few, but only a few, B stars, as there are not many in this part of the sky. The quantities in the fourth and sixth columns of the table are a gage of the distance of the stars to which they refer. It is only necessary to divide these into 337 seconds, which is the angle through which a star distant 1 parsec would have been displaced in the solar motion in one hundred years, to obtain the distances in parsecs. Thus the 240 stars belonging to types A-F, and brighter than 9.5 magnitude, are at an average distance of 170 parsecs.

The first point to notice is that parallactic motions of stars fainter than 9.5 magnitude are always considerably less than the corresponding quantities for stars brighter than 9.5 magnitude. This is, of course, because the faint stars are, on the whole, further away. The average distance of stars of magnitude 10.0 is approximately 1¾ times as great as for a star of 8.0 magnitude.

The next point is the very great distance of the red stars. The 269 faint red stars are very nearly 1,000 parsecs away, or 200 million times as distant as the sun. At this great distance the sun would appear as of magnitude 15.5, but these stars vary in magnitude from 9.5 to 11.0, and are therefore intrinsically from 250 to 63 times as bright as the sun. Now it happens that among the stars nearest to the sun the distances of which have been actually measured there are several red stars, and these are all very much fainter than the sun. It has been suggested by Prof. Russell and Prof. Hertzsprung independently that the red stars are of two distinct classes, which they call the giants and the dwarfs, and that, in accordance with Sir Norman Lockyer's views, the giant red stars are in an early stage of evolution, and are increasing in temperature; while the dwarf stars are at the other end of the series, and are growing colder and darker.

Leaving the red stars, it is seen that the stars the color indexes of which lie between −1 and +4 are nearer to us than the groups on either side of them. These stars are those the spectra of which are of the types F and G in the Harvard notation, and are the stars most like the sun. The mean distances of these stars is only 130 parsecs for the stars brighter than 9.5 magnitude, and 215 parsecs for the stars fainter than 9.5 magnitude. At this distance the sun would be of magnitude 12.1. It follows that these stars are, on the average, from two to eight times as bright as the sun. The A-F stars are a little, but not much, farther away, the stars fainter than 9.5 magnitude being at an average distance of 263 parsecs. At this distance the sun would have a magnitude of 12.5, and these stars are from sixteen to four times as luminous as the sun.

It has been shown how the knowledge that the solar system is moving in a known direction with a velocity of 19.5 kilometers per second leads to a determination of the distances of groups of stars the angular movements of which are known. The hypothesis made is that in a number like one hundred or two hundred stars, the irregular angular movements due to the motions of the stars themselves neutralize one another on the average. But this is only the mean distance of the group, and some are much nearer and some much farther. The distribution of the stars about this mean distance may be derived from the proper motions, if we know how the linear velocities are distributed. I shall apply this method to the group of stars which are like the sun in type of spectrum, and therefore, presumably, of like temperature and physical constitution.

Dividing these into three classes according to their magnitude, it is found that their parallactic motion due to the sun's movement, and their average motion in the perpendicular direction due to their own peculiar movements, are as follows:

	No.	Parallactic motion	Av. cross motion	Ratio
		"	"	
All stars down to 11.0m.	1,247	1.92	±1.67	0.87
Stars brighter than 10.0m.	470	2.50	±2.10	0.84
Stars brighter than 9.0m.	148	3.34	±2.90	0.87

In the last column is given the ratio of the average cross motion to the parallactic motion. The agreement of the numbers shows that the bright stars and the faint stars have the same average velocity. Taking the velocity of the sun as 19.5 kilometers a second, it follows that the average velocity of these stars in the direction perpendicular to the sun's motion is 13.7 kilometers a second.

We shall now make the assumption that some of these stars are moving faster than this velocity and some slower, just as errors of observation are distributed about a mean error. With a mean velocity of 13.7 kilometers a second, there will be in 1,000 stars

231	with velocities	0 to 5 km/sec
208	" "	5 " 10
175	" "	10 " 15
141	" "	15 " 20
163	" "	20 " 30
59	" "	30 " 40
18	" "	40 " 50
1	" "	>50

If now the observed proper motions are arranged, it is found that the number less than any value τ can be represented satisfactorily by an algebraic formula

$$N \frac{\tau}{(\tau^2 + a^2)^{\frac{1}{2}}}$$

mean value of τ. The following table shows the actual number of stars with proper motions between certain limits, compared with the number given by the formula:

TABLE VII.

Limits of proper motion	No. of stars observed	No. given by formula	Difference
0″ to 1″ a century...	427	429	−2
1 " 2 " ..	346	337	+9
2 " 4 " ..	324	332	−8
4 " 7 " ..	105	103	+2
7 " 10 " ..	25	22	+3
>10 " ..	20	19	+1

We may take it that the formula substantially represents the observed facts. With the proper motions distributed according to this formula, and the actual velocities distributed according to the law of errors, the distribution of the stars in distance can be determined, and it is found that these 1,247 stars are distributed in space as shown in Table VIII.

TABLE VIII.

NUMBER OF SOLAR STARS (TYPES F AND G) AT DIFFERENT DISTANCES.

Distance (parsecs)	Out of total 1,247 stras	Out of 470 stars brighter than 10.0m.	Out of 148 stars brighter than 9.0m.
<100	121	76	40
100—200	298	161	65
200—300	332	136	34
300—400	254	68	8
400—500	146	23	1
500—600	65	5	
600—700	23		
>700	5		

The most remarkable feature of this table is that 70 per cent of the stars lie between the narrow limits of one hundred and four hundred parsecs.

I have treated the 470 stars which are brighter than 10.0 magnitude and the 148 brighter than 9.0 magnitude in a similar manner. The results are given in the third and fourth columns of Table VIII. Taking the differences, the distribution in distance of the 777 stars of magnitude is 10.0-11.0 and of the 322 stars of 9.0-10.0 magnitude is found.

To compare the intrinsic magnitudes of the stars it is convenient to take limits of distance in geometrical progression with a common ratio 1.259 (log = 0.1), e. g., 40, 50, 63, 79, 100, 126, etc., parsecs. These limits correspond to a change of half a magnitude in the intrinsic brightness of the stars which are of the same apparent brightness. Confining our attention to the stars of apparent magnitude 10.0 to 11.0, or, speaking broadly, stars of 10.5 magnitude, the limits 50-63 parsecs contain stars half a magnitude brighter, and distributed over twice the volume of those contained between the limits 40-50 parsecs.

If we may assume that the actual density of the stars is the same in all parts of the space with which we are dealing, we obtain by reasoning of this kind the number of stars between different limits of absolute brightness. The following table shows the number of stars of different luminosities in a sphere of one hundred parsecs radius:

Luminosity ☉ = 1	No. of stars	
	10.0m.—11.0m.	9.0m.—10.0m.
0.40 to 1.0	16,000	18,000
1.0 " 2.5	9,500	11,200
2.5 " 6.3	5,750	7,300
6.3 " 16	2,570	3,600
16 " 40	502	1,040
Brighter than 40..........	14	68

The results in the second column have been obtained by considering the faintest stars, those from 10.0 to 11.0 magnitude. If the class brighter is taken, those stars which appear to be of magnitudes 9.0 to 10.0, we find in a similar way the quantities given in the last column.

There is an increasing divergence between the results. Now it is to be remembered that these figures have been derived from regions at different distances from the sun. Thus the stars which are between sixty and forty times the brightness of the sun, and which are apparently of magnitude 10 to 11, lie between 398 and 631 parsecs, while those which are apparently of 9.0 to 10.0 magnitude lie between 251 and 398 parsecs.

We may conclude, therefore, that the density of this class of stars is somewhat less at this greater distance from the sun. Following out this line of reasoning, I have found the diminution of density of the stars to be as follows:

Distance	Density	Distance	Density
At 50 parsecs....	1.30	At 300 parsecs....	0.48
" 100 "	1.00	" 400 "	0.32
" 200 "	0.70	" 500 "	0.21

Although much weight cannot be attached to the exact figures, one seems justified in saying that there must be a very considerable falling off in the density of the stars between the distances of 100 and 500 parsecs. A falling off in the total density of the stars would affect the tables giving the proportion of stars of different brightness, and would increase considerably the proportion of bright stars.

Although the conclusions presented in this paper have been derived from a study of the proper motions of the stars in a small area of the sky, and may be somewhat modified by the investigation of other regions, they may be considered as fairly applicable to the stars in general. The limiting magnitude of the stars that have been considered is nearly 11.0 (on the Potsdam scale), and there are, in the whole sky, half a million stars brighter than this limit of magnitude.

It may be said of them that:

(1) On the whole, the yellow stars, the stars like the sun in physical conditions, are the nearest.

(2) They lie within fairly narrow limits of distance —80 per cent are between 100 and 500 parsecs, 10 per cent nearer than 100 parsecs, and 10 per cent farther away than 500 parsecs.

(3) Going from the yellow to the blue or the orange stars, the average distances increase.

(4) The red stars are at great distances—an average of about 1,000 parsecs.

(5) The stars vary greatly in *intrinsic brightness*. The red stars are specially luminous, being on an average one hundred times as bright as the sun.

(6) Considering all the stars down to this limit of magnitude, from 90 to 95 per cent are intrinsically more luminous than the sun.

(7) When, however, the luminosity of the stars in a given volume of space is considered, there are found to be far more faint than bright stars. There is no contradiction between this conclusion and the last one, because the more distant bright stars are visible, while we only see the faint ones which are comparatively near.

(8) Evidence has been found that the stars thin out very materially at great distances from the sun.

These conclusions are in harmony with the conception of a finite stellar universe. Most of the stars we see, and a great many fainter ones, are within the distance of 1,000 parsecs. Doubtless the stars extend to much greater distances, perhaps ten times as far or farther, but we can scarcely doubt that we are near the middle of a finite group of stars, and that the extent of this group is of the order of 1,000 to 10,000 parsecs.

Another System of Generating Electricity

ONE of the latest propositions for producing electricity commercially is the application of thermo-electric couples placed around a heated flue. These couples are composed of an element made of a special secret alloy and a copper-nickel element. These elements are separated by a layer of mica insulation and are joined together at their hot ends by a band of electrolytically deposited copper. Five of these elements are connected together in series to form a unit, and a suitable number of these units, which are wedge shaped, are formed into a ring that surrounds the heated flue, from which it is insulated by an interposed layer of mica to prevent short circuiting the units. The unheated ends of the elements are kept cool by circulating cold air around them. It is said that the cost of installing such a sytem, as compared with steam, gas and oil operated engines, is as 13 compared to 26, 30 and 38, respectively, while the cost of producing electricity by this arrangement compares with the above sources as 5.6 to 24, 16.5 and 19.3, respectively, not taking into consideration the cost of depreciation or attendance of the steam, gas and oil plants.

Dr. Bose's Visit to America

PROF. J. C. BOSE, whose discoveries regarding the continuity of physiological response in the plant and animal created great interest in England and the Continent, is now in America on scientific mission from the British government. Prof. Bose will exhibit his resonant recorder at Philadelphia before Section G of the American Association for Advancement of Science on the 29th of December. This instrument records time intervals as short as the thousandth part of a second, and measures the perception time of a plant. On the 11th of January Prof. Bose will give a discourse on "Plant Autographs and Their Revelations," illustrated by original experiments, before the Academy of Sciences, New York. Before his return to Europe Dr. Bose will lecture before the Columbia University, the Academy of Sciences, Washington; the Philosophical Society of Philadelphia, the Twentieth Century Club, Boston; the Universities of Chicago, Wisconsin, Illinois, and Michigan.

Locomotive Headlights

IT is stated by an authority on the subject, that the intensity of the head-light of a locomotive should not be greater than fifteen to twenty candle power per square inch of its projected area, hence a lamp of 3,000 candle power, with a 16-inch reflector, will give an illumination within the maximum limit. The chief function of a head-light is to warn persons ahead of the approach of the train, as no commercially practical light would enable the engineer to see a dark object, like a man, more than 500 feet. The light, however, serves as a warning in many cases at a distance of 25 miles, and it is also useful to the engineer in distinguishing landmarks, whistle boards and similar objects.

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Table of Contents

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